NPS-55SS72031B
6 March 1972

A SURVEY AND ANALYSIS OF HIGH DENSITY MAGNETIC STORAGE DEVICES

by

N. F. Schneidewind
G. H. Syms
T. L. Grainger
R. J. Carden

INFORMAL DOCUMENT FOR INTERNAL DISTRIBUTION

This material is designed for expeditious transmittal of specific, interim information of immediate interest to project sponsor codes or personnel to which it is addressed. It is not to be cited in bibliographic references. Those portions of the information therein, appropriate for concurrent or later technical report publication, will be available to respective distribution lists and to library systems. Additional copies are not normally available.

NAVAL POSTGRADUATE SCHOOL
Monterey, California

TABLE OF CONTENTS

I. Summary

A survey and analysis has been made of high density peripheral storage devices for the Navy Fleet Material Support Office. The purpose of the survey was to identify the availability of high density devices and their potential for application to naval ADP systems. The survey considered magnetic tapes, discs, drums and super density devices. The focus of the survey was on peripheral units which are compatible with IBM and Univac equipment. In each equipment category, performance, cost and performance/cost relationships were identified and analyzed. These relationships were used to classify the performance-cost of each equipment category in order to identify similarities and dissimilarities within and between equipment categories. In addition, naval users of high density devices were contacted to obtain data on implementation experience in the areas of performance, compatibility, service and reliability.

For most peripheral categories, significant performance and cost advantages were identified in favor of independent manufacturers of replacement equipment. These differences are based on manufacturer design specifications and information appearing in technical articles. It was impossible to obtain quantitative data from users by telephone which might corroborate manufacturer claims. Most naval users were negative in their qualitative appraisal of independent manufacturer disc unit performance, reliability and service. Except for service, most naval users were satisfied with independent manufacturer tape units. However, for various reasons which are discussed in the report, user appraisals must be discounted in certain respects.

Based on this survey, high density devices are readily available and the application potential is very great. However, information concerning equipment potential needs to be augmented by definitive information concerning actual performance in Naval installations. A major requirement for Phase II which was identified is the need to visit selected users of high density equipment in order to obtain detailed data on equipment performance, compatibility, service and reliability. Only in this way can manufacturer claims concerning superior performance be proved or disproved.

II. Project Description

A. Objectives

In recognition of the growing importance of high density magnetic recording and its potential for improved Naval supply ADP operations, the Fleet Material Support Office (FMSO) is sponsoring a Digital Recording Technology Project, conducted by faculty and graduate students of the Naval Postgraduate School. The project is being conducted in two phases. The first phase, which is the subject of this report, involves a survey and analysis of technical literature and manufacturer specifications in order to determine the characteristics and availability of high density magnetic recording equipment. In addition, comments were obtained from users concerning their implementation experience with high density magnetic storage devices.

In the second phase, the information collected during the first phase will be used to determine the potential for applying high density recording devices in Naval supply applications.

B. Scope

The survey included magnetic tapes, discs and drums. Units which are plug compatible with IBM peripheral equipment were emphasized, since the Navy currently has a major interest and investment in this replacement market. Due to the smaller number of installations, UNIVAC compatible units were considered to a lesser extent.

As used in this report, high density refers to greater than 800 bytes per inch in the case of tapes and greater than 1000 bits per inch in the case of discs and drums.

Users contacted consist of Navy installations which have installed IBM or UNIVAC plug compatible units under ADPESO contracts.

C. Approach

Over 100 technical articles, manufacturer brochures and advertisements were read, analyzed and documented. The list of references consulted appears in the Appendix. Occasional references to this list appear in the report in the form (10), which refers to reference number 10 in the list of references.

A data collection form was designed and utilized for recording technical and price data for tapes, discs and drums. This data was too detailed and voluminous to reproduce in this report. The raw data forms can be made available should a need exist. The tables and graphs which appear in the report are summaries of the raw data.

Performance measures were calculated for peripheral units and related to each other and to cost in order to identify the important performance parameters and the relationships between performance and cost.

Navy users of plug compatible units were contacted by telephone for the purpose of obtaining comments regarding implementation experience with high density replacement devices. A list of the installations and computer configurations is contained in the Appendix.

Personnel at ADPESO were contacted in order to obtain names of plug compatible installations and contract and price information regarding replacement equipment at these installations. ADPESO contracts and pertinent articles were reviewed.

An important disclaimer to the information and conclusions which appear in this report is that cost-performance data for various manufacturer units are based on manufacturer specifications and information which has appeared in technical journals and in the industry press. No conclusions should be drawn from this report concerning the actual or realizable cost-performance of installed units. No quantitative data concerning the actual performance of peripheral units in naval computer installations was available. Numerous subjective evaluations of equipment performance was provided by certain users. As explained later, this information is suspect in certain respects. What the information does provide is an indication of the availability of high density devices and the potential for their application in naval ADP systems.

III. Major Findings

A. Magnetic Tape Units

1. Summary of Characteristics

It was found convenient to analyze and discuss magnetic tape units in terms of IBM compatible groups. This is due to the large plug-to-plug compatible market which has evolved in recent years for tapes and other peripheral equipment. Plug-to-plug compatible means that:

- tapes written on IBM units can be read by compatible units
- tapes written on compatible units can be read by IBM units
- no changes in hardware or software in the IBM computer system are necessary in order to operate compatible tape units

In the case of tapes, technical characteristics among manufacturers are almost identical for a given IBM compatible group. Differences in performance characteristics are between rather than within compatible groups. Tape units were categorized into the following IBM compatible groups:

2401-5
2401-6
2420-5
2420-7
3240-3
3240-5
3240-7

The tape units which were analyzed are listed in Table 1. All tape units in the table are available with a recording density of 1600 bpi. Thus, based on the definition used in this report, all tapes in the sample are high density units. All tape speeds in the sample equal or exceed 75 inches per second. Table 2 shows the characteristics which are common in each compatible group. Based on the contents of the table and other information, IBM compatible tape characteristics may be summarized as follows:

- Phase encoding is used with 9 track, 1600 bpi tapes
- NRZ recording is used with 9 track, 800 bpi and 7 track, 556 or 800 bpi tapes
- The following compatible groups provide single density (1600 bpi) and dual density (800 and 1600 bpi).

TABLE 1

SELECTED MANUFACTURERS OF COMPATIBLE TAPE UNITS

Manufacturer	Tape Type and Model Number						
	2401-5	2401-6	2420-5	2420-7	3420-3	3420-5	3420-7
Ampex	TM 1624V TM 20405	TM 1624VI TM 20406	TM 20245	TM 20247			
Potter	SC 2405	SC 2406	AT 2425	AT 2427	AT 3423	AT 3425	AT 3427
Telex	4852	4862	5420-5	5420-7			
Texas Instruments	924-5	924-6			934-3	934-5	934-7
Storage Technology		ST 2460	ST 2450	ST 2470	ST 3430	ST 3450	ST 3470
Data Processing Financial & General		DPF 2406	DPF 2425	DPF 2427			
Bucode (OEM)				2024-7			
IBM	2401-5	2401-6	2420-5	2420-7	3420-3	3420-5	3420-7

TABLE 2

COMPATIBLE MAGNETIC TAPE UNIT COMMON CHARACTERISTICS
Tape Type

Characteristic	Units	2401-5 Single Density	2401-5 Dual Density	2401-6 Single Density	2401-6 Dual Density	2420-5 Single Density	2420-7 Single Density	3420-3 Dual Density	3420-3 7 Track Dual Density	3420-5 Dual Density	3420-5 7 Track Dual Density	3420-7 Dual Density	3420-7 7 Track Dual Density
Density	bytes/inch	1600	800/1600	1600	800/1600	1600	1600	800/1600	556/800[a]	800/1600	556/800[a]	800/1600	556/800[a]
Speed	ips	75	75	112.5	112.5	100	200	75	75	125	125	200	200
No. of Tracks		9	9	9	9	9	9	9	7	9	7	9	7
Recording		Phase	NRZ/Phase	Phase	NZR/Phase	Phase	Phase	NRZ/Phase	NRZ	NRZ/Phase	NRZ	NRZ/Phase	NRZ
Transfer Rate	k bytes/sec	120	60/120	180	90/180	160	320	60/120	31.3	100/200	52.2	160/320	83.5
I.R.G. Size	inches	.6	.6	.6	.6	.6	.6	.6	.75	.6	.75	.6	.75
Time to Read Reel	minutes	6.40	6.40	4.27	4.27	4.80	2.40	6.40	6.40	3.84	3.84	2.40	2.40
1000 Byte Record + I.R.G.	inches	1.23	1.85/1.23	1.23	1.85/1.23	1.23	1.23	1.85/1.23	3.15	1.85/1.23	3.15	1.85/1.23	3.15
1000 Byte Record Time	ms	16.3	24.7/16.3	10.9	16.4/10.9	12.3	6.13	24.7/16.3	42.0	14.80/9.80	25.2	9.25/6.13	15.75
Rate for 1000 Byte Records	records/sec	61.3	40.5/61.3	91.7	61.0/91.7	81.6	163.3	40.5/61.3	23.8	67.6/102.0	39.7	108.1/163.3	63.5
1000 Byte Records/Reel	thousands	23.5	15.6/23.5	23.5	15.6/23.5	23.5	23.5	15.6/23.5	9.1	15.6/23.5	9.1	15.6/23.5	9.1
Backward Read		Yes[b]	Yes[b]	Yes[b]	Yes[b]	Yes[b]	Yes[b]	Yes	Yes	Yes	Yes	Yes	Yes
Automatic Thread		No[d]	No[d]	No[c,d]	No[c,d]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[a] Six bit characters per inch. Calculations are in terms of bytes. [b] No for Telex. [c] Yes for Storage Technology. [d] Yes for Ampex.

2401-5
2401-6
3420-3
3420-5
3420-7

. 2420-5 and 2420-7 groups provide only 1600 bpi density for 9 track tapes

. In addition to providing dual density for 9 track tapes, the 3420-3, 3420-5, and 3420-7 groups provide dual density (556/800 bpi) for 7 track tapes. These tapes are compatible with the IBM 729 series. It should be noted that density specifications for 7 track tapes are in units of 7 bit (6 data plus 1 parity) frames per inch. These densities must be multiplied by .75 in order to obtain equivalent bytes per inch and transfer rates in bytes per second. In Table 2, transfer rates are calculated in terms of 417 bytes per inch (556 frames per inch) for 7 track tapes. These tapes can also be operated at single density, 1600 bpi, 9 track, phase encoded.

. All tapes are one-half inches wide.

. All 9 track tapes employ a .60 inch inter-record gap.

. All 7 track tapes use a .75 inch inter-record gap.

. With one exception, all tapes can be read backwards.

. Automatic threading is available for all tapes in the 2420 and 3420 groups and for some tapes in the 2401 groups.

. The primary distinguishing technical feature among groups is tape speed.

Since densities and inter-record gap sizes are standard for a given number of tracks, the only parameter which contributes to variations in transfer rate is tape speed. In addition, there is a variation in rewind time of between .75 to 2.17 minutes.

When evaluating tape units, caution must be exercised in comparing performance figures. Different recording techniques employ different error checking and tape synchronization methods resulting in a variation in the number of non-data characters per block. Seven track NRZ tapes use five non-data characters per block for error checking; nine track, NRZ tapes use 10 non-data characters per block. Nine track phase encoded tapes use 82 non-data characters per block for synchronization purposes. Also, different density tapes may use the same inter-record gap size. These characteristics cause the throughput ratios for

tapes with different densities to be considerably less than the density ratios. Presented below is a comparison of three recording technique/track arrangements. The ratio of transfer rates are computed using the same tape speed for each tape. For a 1000 byte record, a doubling of the density results in only a 45 per cent improvement in transfer rate; for a 100 byte record, the improvement is only 3 per cent.

	7 Track NRZ,600bpi*	9 Track NRZ,800bpi	9 Track PE,1600bpi
Non-data characters per record	5	10	82
Inter-record gap (inches)	.75	.60	.60

1000 Byte Records

Bytes/Inch	Density Ratio	Transfer Rate Ratio
800/600	1.33	1.30
1600/800	2.00	1.45
1600/600	2.67	1.89

100 Byte Records

Bytes/Inch	Density Ratio	Transfer Rate Ratio
800/600	1.33	1.26
1600/800	2.00	1.03
1600/600	2.67	1.30

* 800 - 6 bit frames per inch = 600 bytes per inch

Another point is the importance of tape speed as a determinant of tape performance. This point is illustrated in Figure 1, where transfer rate for 1000 byte records is plotted against tape speed for different densities and inter-record gap size. For example, if the speed of an 800 bpi 9 track tape is increased from 100 to 200 inches per second, the transfer rate for 1000 byte records will increase from 55 to 108 records per second (100 per cent increase). However, increasing the density from 800 to 1600 bpi for a speed of 100 inches per second, only increases transfer rate from 55 to 82 records per second (50 per cent increase).

Also plotted in Figure 1 is reel capacity in number of 1000 byte records as a function of density for two inter-record gap sizes. Density, of course, is an important determinant of tape capacity. Inter-record gap size is not important in determining capacity for large record sizes but would be very important for short records where its size is significant in relation to record size.

In summary, variations in performance among manufacturers is negligible. This is to be expected, since the tape units in each group were designed to be compatible with IBM. There is also a great deal of standardization across compatible groups, with speed being the primary and an important distinguishing feature.

2. Cost-Performance Relationships

In contrast to performance, price is definitely non-standard. This is shown in Figure 2 and Figure 3, where rental rate is plotted against selected performance factors. It can be seen that there is a significant spread in rental rate, with IBM consistently being the most expensive. The spread between IBM and competitor prices is even more pronounced than Figures 2 and 3 indicate, since current prices are shown for IBM, whereas October 1970 prices are shown for independent peripheral manufacturers. Since October 1970, price reductions have been made by the independents. Current prices under ADPESO contracts for selected independents are compared with current IBM prices in Table 3. These prices apply to dual density (800/1600bpi), 9 track tapes. IBM rentals are current price list rates. It is possible that IBM prices would be lower for large quantities under an ADPESO contract. Even allowing for this possibility, it is clear that there is a substantial price difference between IBM and its competitors. However, this is not to suggest that the price-performance of independent units is superior to IBM. Other factors must be considered. These are:

- single versus multiple maintenance representatives
- customer support

FIGURE 1
MAGNETIC TAPE
TRANSFER RATE AND CAPACITY CHARACTERISTICS

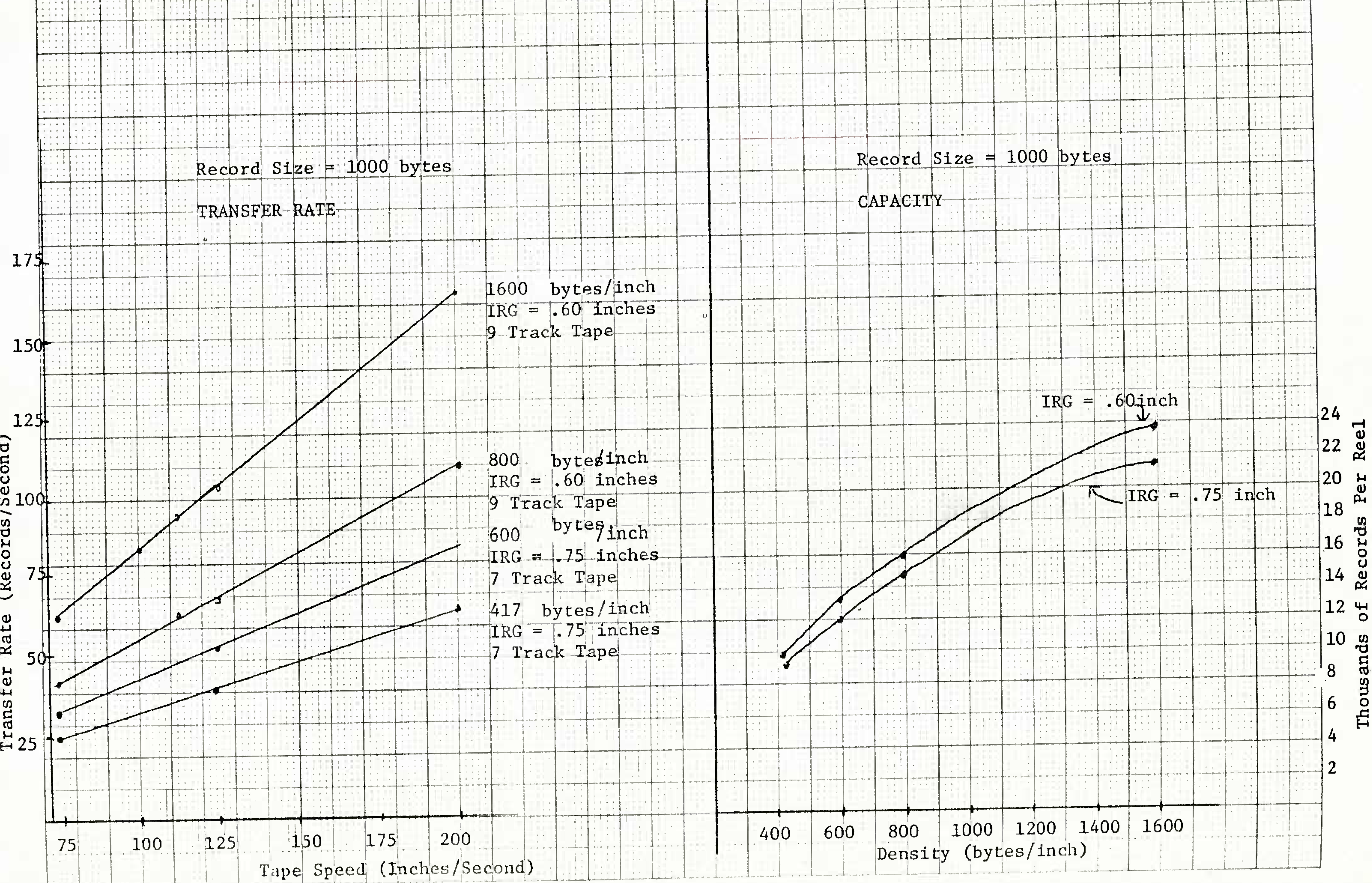


FIGURE 2
TRANSFER RATE - COMPATIBLE MAGNETIC TAPE UNITS

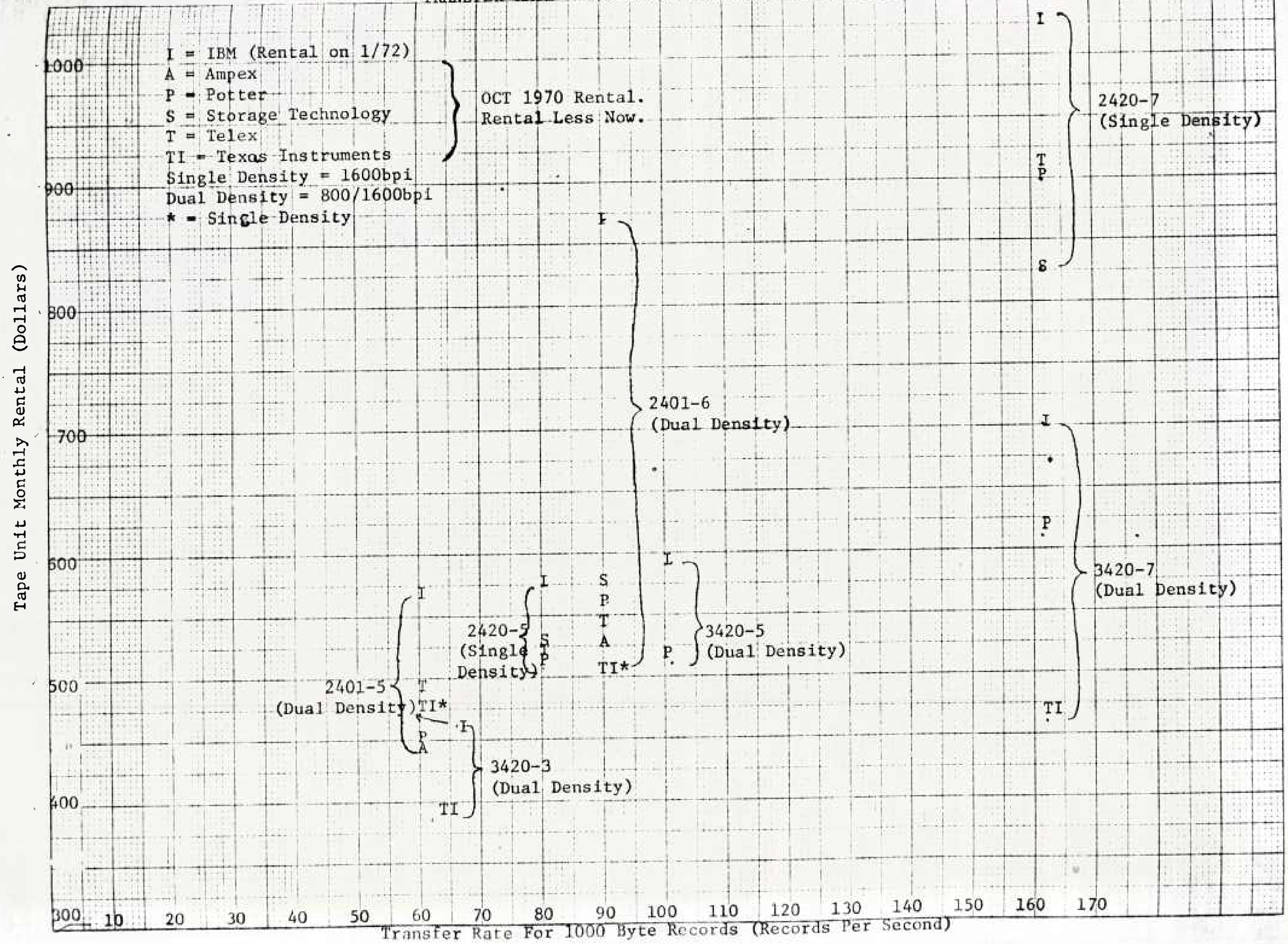


FIGURE 3

READ TIME - COMPATIBLE MAGNETIC TAPE UNITS

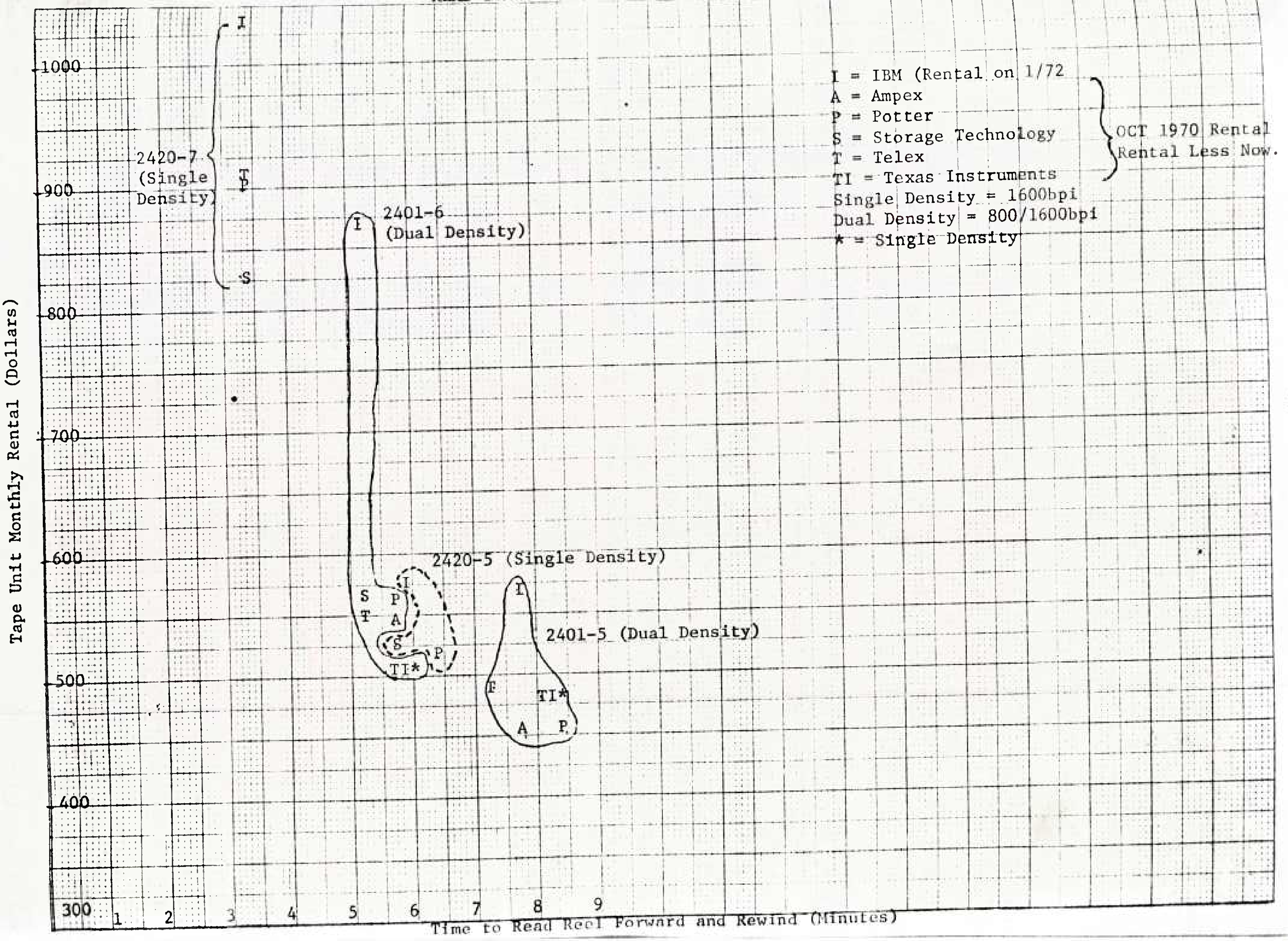


TABLE 3

SELECTED COMPATIBLE MAGNETIC TAPE UNIT COSTS

(Dual Density)

	MODEL TYPE 2401-5	MODEL TYPE 2401-6	Effective Date
	Monthly Rental[1]		
Ampex	$ 369	$ 446	7/21/71
Potter	$ 395	$ 515	6/16/71
IBM	$ 560	$ 860	6/71
	Purchase Price		
Ampex	$12,121	$15,822	7/21/71
Potter	$16,755	$18,200	6/16/71
IBM	$21,630	$33,220	6/71
	Monthly Maintenance		
Ampex	$ 82	$ 98	7/21/71
Potter	$ 100	$ 105	6/16/71
IBM	$ 84	$ 100	6/71

[1] Rental includes monthly charge for principle period of maintenance.

. reliability

. compatibility

Quantitative reliability data were not available from manufacturer specifications and user comments. However, with the possible exception of differences in quality of workmanship, there should be no inherent reliability advantage of one tape over another, since phase encoding is available for all tapes. Phase encoding is superior to NRZ recording in that it has greater ability to correctly read bits from adjacent frames in the presence of tape skew.

Qualitative information concerning user reaction to the ADPESO plug compatible tape procurement is contained in Section III, A, 4.

3. Navy Utilization of High Density Magnetic Tapes

On 25 August 1970 ADPESO completed the largest computer peripheral replacement award in the history of the ADP industry (Ref. 102, 103). This order included 558 tape drives. Tape drive awards were made to Ampex, Potter and Telex. The Telex order was for IBM 729 replacements only. ADPESO contracts specify guaranteed uptime of 95 per cent during the performance period and life of the contract. One hour maintenance response time during the prime shift and two hours at all other times, 24 hours per day, seven days per week is also required. Since all the replacement tape units provide high density recording (1600 bpi), it is clear that large scale installation of high density tapes in the Navy is a reality. User reaction to the tape portion of this procurement is covered in the next section.

4. User Comments on Compatibility, Reliability, and Service of Compatible Tape Drives

Our user survey was of Navy and Marine ADP installations that have recently acquired compatible tape drives. We feel that the experience of these installations is more relevant to a military ADP environment.

The installations surveyed, along with their hardware/software configuration and major applications, are shown in Appendix A. The survey encompassed a broad spectrum of both scientific and commercial applications and large and small configurations.

The specific plug compatible tape drives surveyed are shown below:

IBM Drives Replaced	Replaced By		
	Number	Make	Model
729 V	14	Potter	729-5
729 VI	2	Potter	729-6
	2	Midwestern	4706
	2	Telex	4700
2401-1	2	Potter	SC2401
2401-2	9	Potter	SC2402
2401-3	14	Potter	SC2403
	14	Ampex	TM1624 III
2401-5	17	Potter	SC2405
	5	Ampex	TM1624 V
2401-6	11	Potter	SC2406

a. Compatibility
None of the installations surveyed reported compatibility problems. No major modifications to hardware, software or the facility were required.

b. Reliability
Of 13 installations surveyed only 4 reported more reliability problems than they had experienced with IBM drives. These problems centered around 1) Read/write errors and 2) Mechanical failures such as head replacement.

c. Service
Only 4 of the installations surveyed rated the service from the compatible vendor as good as IBM service. The problems encountered are listed below in the order of frequency of occurrence:

(1) Divided Service Responsibility
Four installations reported difficulty in pinpointing system troubles to a specific vendor's hardware. This created uncertainty over which vendor to call. Unnecessary expense was incurred when the wrong vendor was called.

(2) Customer Engineer Problems
Four installations believed that many of their problems were due to the customer engineer assigned by the compatible vendor. Two of these installations felt that the vendor's overall service policy and response to service problems were good, but that their assigned customer engineer was incapable.

(3) Delays in Getting Spare Parts
Two installations reported delays in getting spare parts. They felt that IBM had spares available on a shorter lead time basis.

d. Conclusion of User Survey
There are several hazards in interpreting the data gathered in the user survey.

(1) Subjective Data
Most of the data gathered was the opinion of the interviewee. Few installations had collected data on the compatible drives. Those that had some data on compatible units did not have comparable data on their previous IBM units. Hence the study results reflect the knowledge and memory of the interviewee.

(2) Position of the Interviewee
Persons interviewed included ADP Director, Operations Manager, and Systems Analyst. The person selected depended on his availability and his specific knowledge of the units under study. The results reflect the perspectives of people at these various organizational levels.

(3) Prior Bias of the Interviewee
This problem is often called the "halo effect." Those persons whose prior belief was that the switch to compatibles was a good idea, will recall information to support that same belief. The converse may also be true.

The above precautions notwithstanding, we think it is useful to relate our general impressions. About 75 per cent of the installations interviewed indicated that the compatible tape drives were worthwhile considering the initial cost savings. Some difficulties to be considered are:

(1) Increased Administrative Load
The use of compatible equipment creates an increased contract administration burden. Also additional office space is required for more customer engineers. This burden falls on the individual commands.

(2) Divided Service Responsibility
One solution here is to call the compatible vendor

first when problems crop up. This has been done in private business (Ref. 105). We understand that ADPESO is working on guidelines in this area.

In summary, the users surveyed appeared to be satisfied with their compatible tape drives despite the minor problems they create.

5. Tape Drive Availability Summary

The table below summarizes the availability of compatible tape drives for each IBM model series.

Compatible with IBM Model	Lead Time Range (months)	Date First Installed Range
2401 series	1-3	OCT 68 - NOV 69
2420 series	1-3	DEC 69 - OCT 70
3420 series	---	Early 1972*

*Projected

B. Disc Units

1. Summary of Characteristics of Equipment Available

a. Number of units compatible with each IBM model category:

Model	Single Density	Dual Density	Higher Density
IBM 2311	17(7.25Mbytes)		
IBM 2314	17(29Mbytes)	11(58M bytes)	4(116/232Mbytes)
IBM 3330			5(100Mbytes)

The classifications of single, dual and higher density pertain to combinations of bits per inch and tracks per inch which provide the capacities shown in the above table.

b. Summary of the Characteristics of Each IBM Model Category. The existing IBM disc drives shown in Table 4 form the basis for comparing the compatible disc drives. Although compatibility will be defined in detail in section IV, basically, plug compatibility implies that installing the new device does not require any changes in hardware or software and performance will not be degraded. A brief description of some of the less obvious specifications listed in the table follows:

DENSITY: BPI - bits per inch
TPI - tracks per inch

RECORDING TECHNIQUE: NRZ (non-return to zero) results in each recording of a change from a zero to a one or vice-versa to be accomplished by a full flux transition.

OF CYLINDERS: Equivalent to the number of tracks on a disk surface.

FIXED HEAD: One read head per track; gives virtually instant track selection.

MOVABLE HEAD: One or more read assemblies, each accessing several tracks.

MIN/CONTR: Minimum capacity in MBYTES (10^6 - 8 bit bytes) for a controller, usually equivalent to one drive's capacity.

MAX/CONTR: Maximum capacity in MBYTES for a controller, maximum configuration of drives per controller.

MIN ACCESS TIME: The cylinder-to-cylinder access time; the time in milliseconds to move the read/write reads from one cylinder to an adjacent cylinder.

AVE ACCESS TIME: Average time in milliseconds to move the read/write read from one cylinder to any other randomly selected cylinder.

MAX ACCESS TIME: The full stroke access time; the time in milliseconds to move the read/write reads from the innermost to the outermost cylinder.

AVE ROTATIONAL DELAY: One-half the rotation time in milliseconds, often referred to as the average latency time.

ROTATIONAL SPEED: Number of revolutions per minute of the disc.

TRANSFER RATE: The rate in KBYTES (10^3 bytes) per second at which data can be transferred to or from the disc drive, once the read/write reads are positioned over the correct cylinder and addressed record.

PURCHASE: Single unit purchase drive without maintenance.

RENTAL: Monthly unit rental with maintenance (single-shift) included.

MAINTENANCE: Monthly payment necessary to obtain single-shift (8 hours) maintenance of the purchased disc drive. This figure includes parts and labor.

Since the project specified high density replacement disks, a list of manufactures of single-density disk drives compatible with the IBM 2311 is not included in this report, although one is available. No high density IBM 2311 compatibles were found. Nor was the single density IBM 2314 included, which has 2000 BPI but only 100 TPI. The general performance characteristics of each high density compatibility class is shown in Table 5. The general characteristics and difference between individual models will be discussed in the following sections.

TABLE 4

EXISTING IBM DISC SYSTEMS

Identification	2311	2314	3330
Disc Pack #	1316	2316	3336
Controller #	2841	2314	3830
Technology			
Density - BPI	1000	2000	4040
- TPI	100	100	192
Recording Technique	NRZ	NRZ	
# of Cylinders	203	203	404
Removable or Fixed Pack	R	R	R
Movable or Fixed Head	M	M	M
Capacity			
Per Drive (MBYTES)	7.25	29	100
Per Cylinder (KBYTES)	36	145	247
Min/Contr. (MBYTES)	7.25	29	200
Max/Contr. (MBYTES)	58	233	800
Performance			
Ave. Access Time (MSEC)	75	60	30
Min. Access Time (MSEC)	25	25	10
Max. Access Time (MSEC)	130	130	55
Ave. Rotational Delay (MSEC)	12.5	12.5	8.4
Rotational Speed (RPM)	2400	2400	3600
Transfer Rate (KBYTE/SEC)	156	312	806

TABLE 4 (CONT)

Cost - Disk drive			
Purchase	21,030	20,490	51,940
Rental (with maint) ($/MON)	570	535	1,300
Maintenance ($/MON)	55	75	170
Cost - Controller			
Purchase	21,790	56,810	95,880
Rental (with maint) ($/MON)	525	1,480	2,400
Maintenance (1 shift) ($/MON)	56	60	145

TABLE 5

GENERAL DESCRIPTION OF IBM COMPATIBLES

Identification	2314 Dual Density Replacements	2314 Higher Density Replacements	3330 Replacements
Technology			
Density - BPI	2,000		
- TPI	200		
Recording Technique	NRZ		
# of Cylinders	400		404
Removable or Fixed Pack	R	R	R
Movable or Fixed Head	M	M	M
Capacity			
Per Drive (MBYTES)	58	116	100
Per Cylinder (KBYTES)	145		247
Min/Contr. (MBYTES)	58	116	100
Max/Contr. (MBYTES)	466	1,800	800
Performance			
Ave. Access Time (MSEC)	35	55	30
Min. Access Time (MSEC)	10	12	
Max. Access Time (MSEC)	60		
Ave. Rotational Delay (MSEC)	12.5		8.3
Rotational Speed (RPM)	2,400		3,600
Transfer Rate (KBYTE/SEC)	312	234	806
Cost			
Purchase (8 Drives + Contr.)	190,000		350,000
Rental with Maint. (Per month)	4,725		7,600
Maintenance (Per month)	688		1,500

2. Performance Summary

a. IBM 2314 Dual Density Replacements

A list of the companies and the models of the 2314 disc drive compatibles which are dual density is:

COMPANY	DRIVE	CONTROLLER
AMPEX	DS 324	
BASF SYSTEMS	214	1014
CALIFORNIA COMPUTER PRODUCTS	CD 22	CD14
	CD 215	CD 1015
CENTURY DATA SYSTEMS	CDS 214	CDS 1014A
CONTROL DATA CORPORATION	23142	
HITACHI	H-85771-2	H85775
INFORMATION STORAGE SYSTEMS	ISS 715	
MARSHALL DATA SYSTEMS	M2900	M2800
MEMOREX	665	661
TELEX	5625	5650

As implied, all dual density IBM 2314 replacements have a capacity of 58 MBYTES per drive vs. 29 MBYTES for the 2314. This doubling of capacity is achieved in a number of ways which will be discussed later in section I. Basically, dual density is achieved by doubling the number of tracks (or cylinders) and consequently the number of tracks per inch. All of the above listed drives are like this except Memorex which doubles the bits per inch instead. As a result, the Memorex drive has a rotational speed of 1200 RPM in order to maintain the compatible data transfer rate of 312,000 BYTES/SEC. The other drives have a rotational speed of 2400 RPM for the same transfer rate. The average access time for the 2314 replacement ranges from 29 milliseconds (MSEC) to 60 MSEC;the minimum access time ranges from 7 MSEC to 12 MSEC the maximum access time ranges from 55 MSEC to 65 MSEC. The average rotational delay is 12.5 MSEC for all drives except Memorex which has an average rotational delay of 25 MSEC.

The IBM 2314 replacements all have movable read mechanisms and removable packs. Most units are able to use the IBM 2316 pack.

All the above drives are IBM plug-to-plug compatible except for the Information Storage System's (ISS), Telex and Ampex drives. The ISS 715 is engineered for practical integration into existing systems with minimum controller and programming changes. This apparently means that ISS supplies the necessary modifications at some extra charges (this may be wavered under an ADPESO Contract). Telex supplies DOS and OS modifications at no extra charge. Ampex offers compatibility with 4 drives; however, 8 drives require softward changes (apparently supplied by Ampex at some extra charge).

b. Higher Density IBM 2314 Replacements

COMPANY	DRIVE	CONTROLLER
CENTURY DATA SYSTEMS	CDS 215	
DATA PRODUCTS	314	7361
	7318	7360/7361
HITACHI	H85771-4	H85775

The higher density 2314 replacements recorded have a capacity per drive of 116 MBYTES, except for the Data Products 314 which has a capacity of 232 MBYTES per drive. The capacity per controller reaches 1.8 billion bytes. The CDS 215 has a removable pack and a movable read mechanism, while the Data Products 314 has a fixed pack.

Hitachi and Century Data Systems offer plug-to-plug compatibility with IBM 360 and 370 systems, while Data Products list their higher density drives as 2314 replacements suggesting possible software modifications.

The IBM 3330, and its compatible disk drives, are also a possible replacement for the 2314 on Systems 360/85-195 and 370.

Table 6 provides a quick reference to some of the IBM 2314 replacement specifications.

TABLE 6

IBM 2314 REPLACEMENT SPECIFICATIONS

Density	Single	Dual		Higher			
Capacity/drive (Mbytes)	29	58		116			232
Capacity/cyl (Kbytes)	145	145	280	145	280	unknown	312
No. cylinders	203	406	203	812	406**	-	745
RPM	2400	2400	1200	2400	2400	-	600*
ave rotational delay (MS)	12.5	12.5	25	12.5	12.5	-	50*
bpi	2000	2000	4000	2000	2200	unknown	6000*
No. Devices	17	10	1	1	1	1	1
Company	-	-	Memorex	Data Products	Hitachi	Century Data 215	Data Products
Device No.	-	-	-	7318	H-85771-4	-	314

* These values are estimates. They were calculated on the assumptions that the disk diameters are the same as 2316 disk packs; the density is higher than 4000 bpi; and the speed is less than 1200 rpm and an integral fraction of 3600 rpm. The first choice for the speed that satisfies these conditions is 600 rpm. Thus, using the fact that 2400 rpm and 2000 bpi produces a transfer rate of 312 Kbytes/sec, and that the Data Products transfer rate is 234 Kbytes/sec, the density was calculated as

$$\frac{234 \text{ Kbytes/sec}}{312 \text{ Kbytes/sec}} \times \frac{2400 \text{ rpm}}{600 \text{ rpm}} \times 2000 \text{ bpi} = 6000 \text{ bpi}.$$

It is believed the Data Products Corp does not advertise the bit density or the rotational speed because it would then be easy to calculate the high rotational delay.

** Two high density disk drives on a single spindle. This means that each cylinder has 40 surfaces instead of 20. It will not accept 2316 disk packs.

c. IBM 3330 Replacements

COMPANY	DRIVE	CONTROLLER
CENTURY DATA SYSTEMS	CDS 230	CDC 1030
CONTROL DATA CORPORATION	9750	
MEMOREX	670	671
POTTER	DD 4330	DC 5830
TELEX	6330	

CAELUS CMCX 3330 DISC PACK

The IBM 3330 and its replacements feature 100 MBYTES capacity per drive, reaching a maximum of 800 MBYTES per controller (8 drives). The CDS 1030 controller can operate 2, 4, 6 or 8 drives. The Potter DD 4330 is a 2-drive unit, using 4 DD 4330's for a complete system. Memorex allows further flexibility in that its 671 controller can have a configuration of from 1 to 8 drives. All the models can use the IBM 3336 disc pack, except for the Memorex 670 drive which uses its own MARK TEN disc pack. Consequently, the packs are all removable and the drives all have a movable read head mechanism.

The average access time for the IBM 3330 replacement ranges from 25 to 30 MSEC. The data transfer rate is 806,000 BYTES/SEC. All of the models feature plug-to-plug compatibility with IBM 360 and 370 systems, except for the CDC 9750 which might need software modifications. The earliest available 3330 replacement model is the CDS 230, scheduled for delivery in March 1972.

As an added note, Caelus offers the CMCX 3330 disc pack which is 100 percent compatible with the IBM 3336 disc pack. The CMCX 3330 has a storage capacity of 100 MBYTES. Each disk surface within the pack can contain up to 404 primary tracks with an additional seven tracks available as alternates. Track density is approximately 200 tracks per inch; bit density is a maximum of 4040 bits per inch.

d. Access Time Summary

The minimum, average and maximum access times are summarized as a function of capacity per controller for all classes of IBM 2314 replacements (replacement of 2314's by 3330's is restricted to system 360/85 - 195 and system 370) in Figure 4. This information is plotted for all devices from all suppliers but in some cases only average access times were available. The reduction obtained in average access time with 2314 replacements is shown in Figure 4. This is in addition to the added capacity. The higher density 2314 replacements, due to their higher capacity, have a higher average access time than the IBM 2314 dual density replacements. Also of interest is the similarity between the IBM 3330 and its replacements.

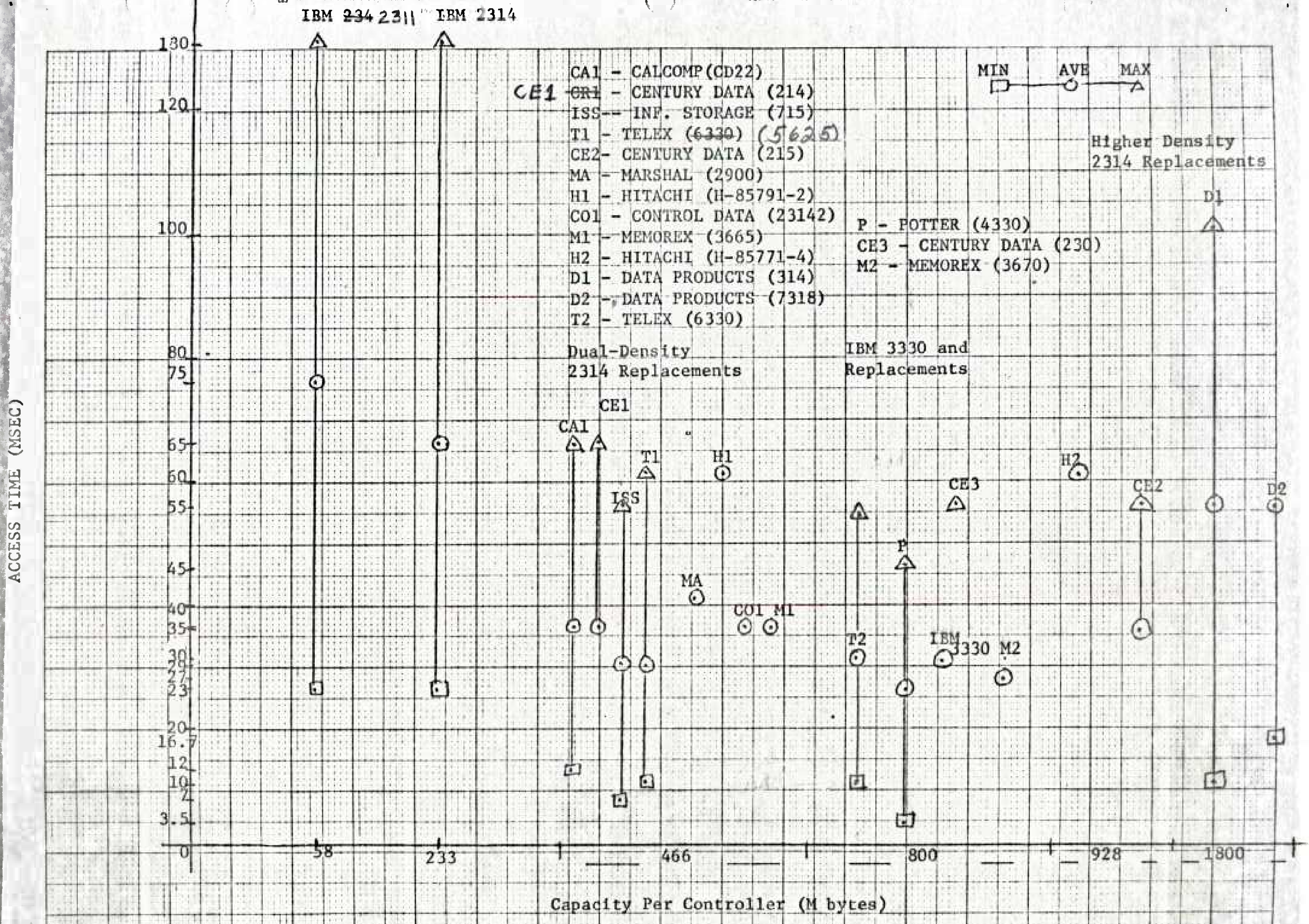


FIGURE 4 ACCESS TIME SUMMARY

3. Cost Summary

a. Purchase

The 2314 dual density replacement price is about $15,000 per drive versus $20,490 per IBM 2314 drive. Where the independent manufacturer provides a controller, its price is about $54,000 versus $56,810 for the IBM 2314 controller. The higher density 2314 replacement which features the 116 MBYTE capacity per drive is quoted at $26,000 per drive. The 3330 replacements are advertised at a savings of from 8 to 18% over the IBM 3330.

b. Rent

The rental prices quoted include a one shift (8 hour) maintenance. The 2314 dual density replacement drive rents for about $525 per month versus $535 per month for the IBM 2314. Where controllers are offered, the rent is $1,210 per month as opposed to $1,480 for the IBM controller. In a configuration of one controller, eight drives and a spare, the 2314 replacements rent for about $4,725 per month.

c. Maintenance

Maintenance costs are for a one shift per day monthly rate for any purchased disc system. The 2314 dual density replacements have an average maintenance cost of $78 per month for a drive and $64 per month for a controller. The charge is $75 per month for a drive and $60 per month for a controller. Thus, there is very little saving in maintenance cost. However, there can be a considerable saving in purchase price or rental by using compatible devices.

4. Performance/Cost Summary

a. Purchase Cost Versus Capacity

Figure 5 is a plot of purchase cost for 8 drives and a controller versus the capacity of 8 drives over all models. As would be expected the cost generally goes up as the capacity is increased. In the case of the 2314 dual density replacements, however, a double capacity is obtained for the same price. Century Data Systems offers a drive with four times the 2314 capacity at about the same price as the double density 2314 replacements. Again, it can be seen that the IBM 3330 does not differ appreciably from its replacements in the cost versus capacity category.

Figure 6 was developed to get a better cost/capacity correlation among all models. Figure 6 is a plot of the purchase cost/MBYTE versus the capacity for 8 drives. It is obvious from the figure that for large capacity systems, a cost savings of three to five times can be achieved by buying 2314 replacements. Considering the wide range of capacities of the different replacement groups, there is surprising little variation in the cost per MBYTE. Note the

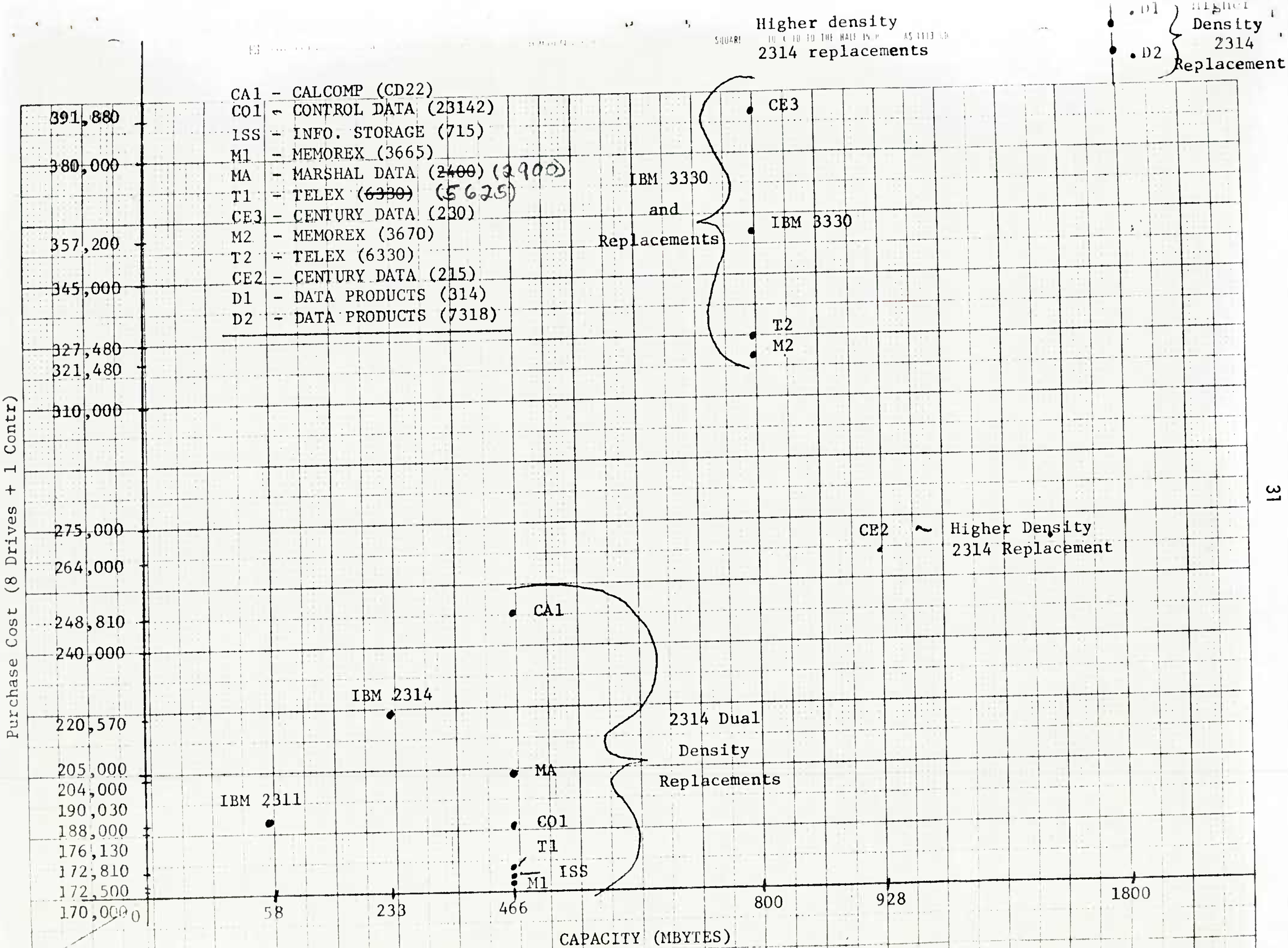


FIGURE 5 COST SUMMARY FOR DISKS

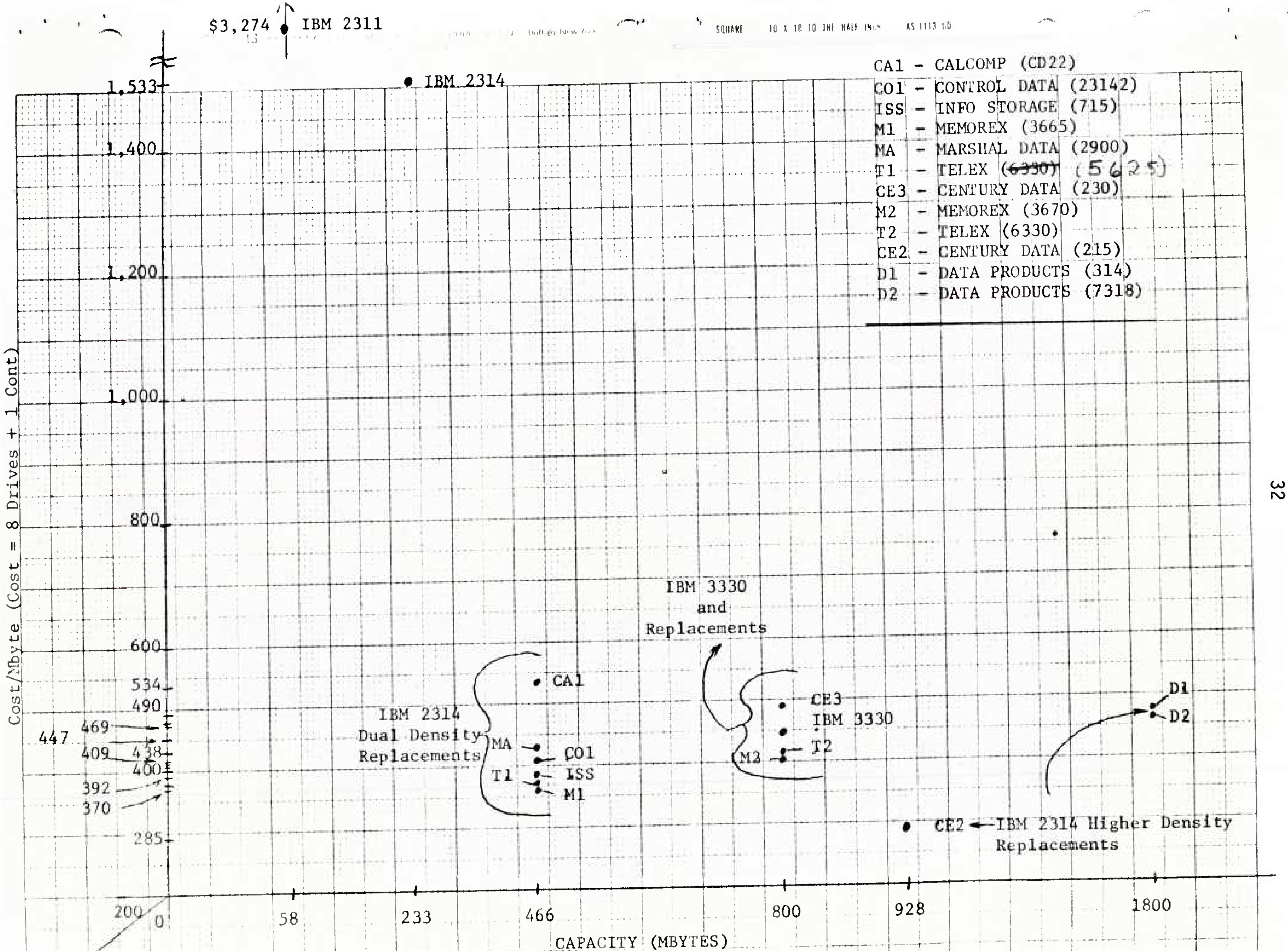


FIGURE 6 COST/MBYTE VS CAPACITY

high capacity and competitive cost/MBYTE of the IBM 2314 higher density replacements, especially Century Data 215, as compared to the IBM 3330 and its replacements. Again, the IBM 3330 does not significantly differ in price-performance from its replacements.

b. Purchase Cost Versus Average Access Time:

Figure 7 is a plot of the purchase cost of 8 drives and 1 controller versus the average access time in milliseconds over all models. Evident again is the advantage of the IBM 2314 dual density replacements over the IBM 2314. Based on cost, the 2314 dual density replacements are better than the 3330 replacements for the same approximate average access time of 30 milliseconds. The IBM 2314 higher density replacements do not compare favorably due to their high cost and relatively high access time. The higher density Century Data Systems 215 has better price-performance than the two higher density replacements offered by Data Products. The IBM 3330 and its replacements differ slightly in price-performance.

Figure 8 is a plot of the purchase cost/MBYTE versus average access time in milliseconds over all models. From the figure, it is obvious that an access time of about half that of IBM 2314 can be obtained with the replacements, as well as the three to five time cost saving mentioned previously. It is interesting to note the cluster of points between 27 and 40 milliseconds and between 370 and 440 dollars per MBYTE. Obviously, there is no appreciable difference between the IBM 2314 replacements and the IBM 3330 and its replacements, when considering these parameters. Of special interest again is the favorable performance of the Century Data Systems 215, which is about one-fifth the cost/capacity and has about one-half the access time of the IBM 2314.

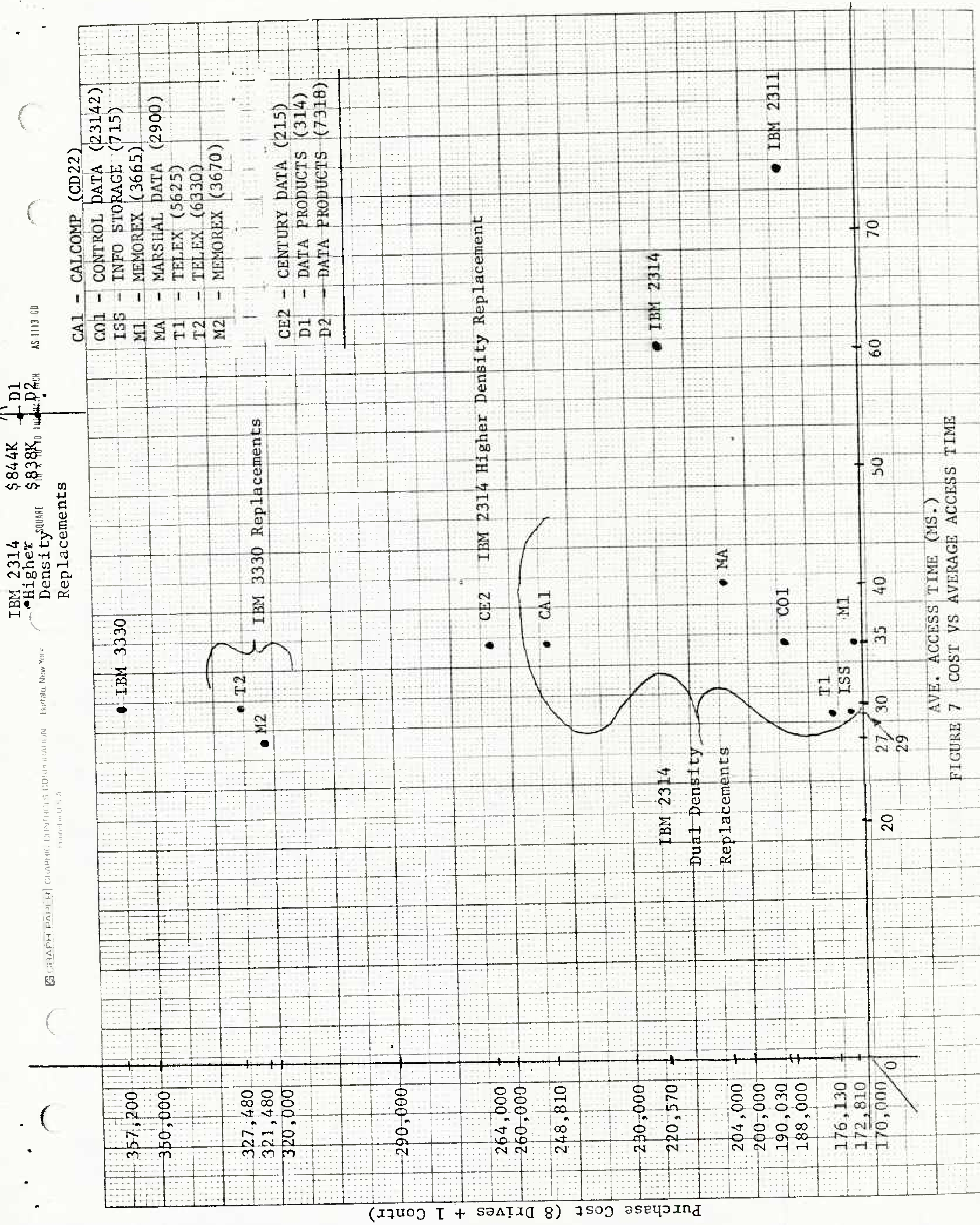


FIGURE 7 COST VS AVERAGE ACCESS TIME

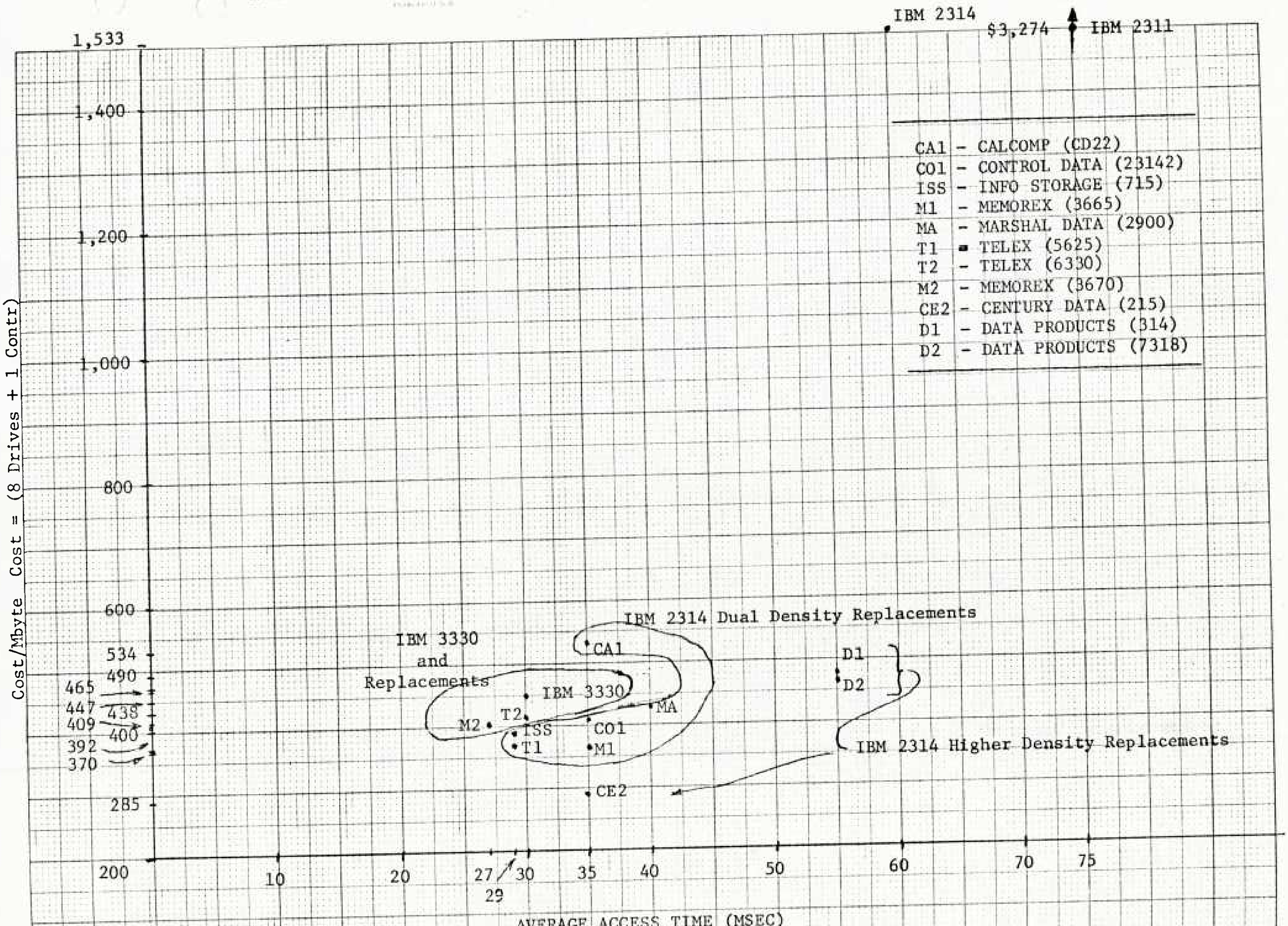


FIGURE 8 COST/MBYTE VS ACCESS TIME

5. User Comments on Compatibility Reliability, Service and Performance of Compatible Disc Drives

Information on the installations surveyed in this section is listed in Appendix A.

The specific plug compatible disc drives and controllers included in this survey appear below.

Replaced Gear			Replacement Gear	
Make	Model	Number	Make	Model
IBM	2311	8	Potter	4311
IBM	2314	1	Memorex	661
		7	Potter	5314
		8	Calcomp	CD14
IBM	2312	8	Memorex	660
		58	Potter	4314
		48	Calcomp	CD12
IBM	2318	8	Calcomp	CD22
Univac	Fastrand		Data Products	Disc

a. Performance
Only one installation in our survey reported any noticeable difference in throughput and response times from the faster plug compatible disc drives. Reliable data was scarce in this area. Another installation used a monitor to detect efficiencies of the Calcomp CD12 (average access time of 33 ms) over the IBM 2314 (average access time of 60 ms). The monitor showed no differences in throughput or elapsed time for the jobs at that installation. Other advantages of the plug compatible discs were more flexible floor layouts due to modular design and faster up time after a disc pack change.

b. Compatibility
None of the installations surveyed required any major modifications to hardware, software, or the facility. At two installations the vendor exceeded the acceptance period by several months. Also another two installations suspected that some of their disc problems resulted from incompatibility between the CPU and the compatible controller. Currently they have no facts to support this suspicion.

c. Reliability
A disproportionate number of installations reported serious and continuing problems with their compatible disc units. All compatible equipment had to meet the 95 per cent up time requirement for the acceptance period. Installations felt, however, that the 95 per cent figure was too low. Equipment could be down a full hour out of a day and still meet the

criterion. Persons interviewed felt that problems with the compatible disc units far exceeded those with IBM equipment.

(1) Six reported frequent head crushes. Three of these indicated that heads had been replaced several times.

(2) Five reported significant and recurring seek and read/write failures.

(3) Two reported controller problems.

d. Service

Since service is vendor related the comments on service on page 17 apply here.

e. Conclusion of User Survey

The hazards of interpreting data from the user survey are listed on page 18. Nevertheless we feel that a general summary is useful. While we felt that most compatible tape unit users were satisfied with their gear, it is apparent that well over half of the compatible disc unit users are not.

A few interviewees were adamant in their complaints and recounted attempts at getting the compatible disc units removed. Others believed that severe pressure on compatible vendors through regional and national offices was necessary to resolve their difficulties. Several installations reported that any initial cost savings on the compatibles was lost due to increased down time and job reruns. One installations reported that the compatible discs were too unreliable to use for storage of the operating system.

Only one installation using Univac compatible disc units was surveyed. They are pleased with all aspects of their plug compatible equipment.

Articles in the popular literature on user experience with compatible disc units are scarce. A survey was done by Computerworld on compatible users in banking and finance, insurance, manufacturing, government, and research. (104.) This survey characterized the compatible disc user as a satisfied customer. It listed advantages for the compatibles in throughput, elapsed time, reliability, service and cost. No user in the Computerworld survey reported any significant problems. All said that they would recommend the compatible units to others.

We can suggest two possible reconciliations between the results of our survey and those of the Computerworld survey. The use of plug compatible units in the Navy has been relatively recent. The installations contacted may still be experiencing start-up problems. Some users in the Computerworld survey did indicate initial implementation problems.

Another factor may be psychological. The Navy purchased the compatible units centrally. If the individual installation had little participation in the decision, they may be resisting this change. Private ADP installations in the Computerworld survey may have been responsible for the decision to switch to compatibles, and therefore will work harder to make the decision pay off.

6. Disc Unit Availability Summary

The table below summarizes the availability of compatible disc units.

Compatible with Make	Model	Lead Time Range (months)	Date First Installed Range
IBM	2314	3-12	MAR 70 - APR 72*
IBM	3330	---	JULY 71 - QTR IV 72*
Univac	Fastrand	3	MAR 71
Non-Compatible		1	SEPT 71

*Projected

C. Drums - Univac Compatibles

1. Summary of Equipment Available

This section will present the replacement equipment for the Univac Fastrand drums. Unfortunately there are still very few competitors to the Univac large back-up storage devices compared to the number of IBM competitors, and yet there are some significant advantages of the Univac compatibles over the original drums.

There are only three companies offering replacement devices that are compatible with the Univac Fastrand drums. These are Ampex Corp with its Amprand II and Amprand III, California Computer Products with its Calcomp 1144DS (two configurations), and Data Products with its DP 7010 and DP 7114. All these units are disk replacements that are plug compatible with the Univac Fastrand II or Fastrand III, and offer significant performance and price advantages. Also, the disks are often claimed to be more reliable than the Fastrand drums.

One major difficulty in completing this portion of the report is the lack of data in the literature. This is probably because of the very few competitors, and these were only recently announced.

2. Performance Summary

Table 7 shows the major performance characteristics of the Fastrand drums and their compatible devices. Note that the DP 7010 is a non-removable disk drive, while the others have removable disk packs. Table 8 shows the access times for drums and their replacements. Of particular significance is that when Univac quotes access time of 5 to 155 MSEC, they mean total access time, including rotational time as well as head positioning time, whereas IBM and its competitors use access time to mean arm positioning time only. (This table also shows some of the difficulties of acquiring data.) Figure 9 shows the average access time versus capacity (in terms of single drum equivalent) for Fastrand and its competitors.

3. Cost Summary

Table 9 summarizes the cost data for the Univac replacements. In several cases the purchase prices were quoted as 20% or 35% below Univac's and this was used to calculate cost. Also the rental for the smallest unit (a drum replacement and a controller) is more often quoted than the rental for separate units or the purchase prices.

Figure 10 shows the monthly rental of a single drum replacement and controller as a function of capacity for all devices, whereas Figure 11 shows the same data but as rental cost per million words of storage capacity. All capacities assume 30-bit words for the Univac 494 computer. Figure 11 shows significant cost advantages of the Data Product devices, if a capacity of two Fastrand II's is needed.

TABLE 7 MAJOR CHARACTERISTICS OF FASTRAN DRUMS AND REPLACEMENTS

COMPANY	UNIVAC	AMPEX	DATA PRODUCTS		CALCOMP
Model No.	Fastrand II / Fastrand III	Amprand II / Amprand III	DP7010	DP 7114	1144 DS
Controller No.	5009-08 (Single), 5009-09 (dual) / Fastrand III	FC 900 (single or Dual) FD 914 Drive	7110/7111		
Drives/Controller	1 to 8 drums	5 to 40 in steps of 5 /8 to 64 in steps of 8	1 to 16	1 to 8	3 to 24 in steps of 3 /4 to 32 in steps of 4
Compatibility	OEM	Plug to Plug on U400 and U 1100 series	U418, 494 and U1100 Series	U400 and U1100 Series	Plug to Plug & Program on U400 and U1100 Series
No. of heads	64/	20	40	40	
No. of tracks/head	192/		812		
Capacity per drum (in M words*)	25.9/38.9	25.9/38.9	25.9	51.8	25.9/38.9
Capacity per Controller (in Mwords*)	207/310	207/310	414	414	207/310
Transfer rate (K words*/sec)	31.6/46.0	84/84	77	52.3	
Comments	Actually 2 drums per Fastrand. Density: 1000 bpi and 106 tpi.	5 and 8 disk drives emulate a Fastrand II and III, respectively. Uses IBM 2314 compatible disk drives. Delivery lead time 90 days.	Non-removable disk replacement	Has been purchased by Univac. First delivered in Mar/71	3 and 4 disk drives emulate a Fastrand II and III, respectively.
Reference Number	77,79,92,112,115,116, /58,113	73, 75	58	73, 80	114

* 30-bit words

TABLE 8

ACCESS TIMES FOR DRUMS AND REPLACEMENTS
(milliseconds)

Device	Arm (Head) Positioning Time			Average Rotational Delay	Total Access Time		
	Min	Ave	Max		Min	Ave	Max
Fastran II	30	57	86	35	5	92	155
Amprand II	8	32	55	12.5	--	44.5	80
Calcomp 1144DS*							
Fastran III	30	57	86	35	5	92	155
Amprand III	8	32	55	12.5	--	44.5	80
DP 7010		55		17		72	
DP 7114	10	70		17		87	

* No information available

Figure 9 Average Access Time and Capacity
For Univac Drums and Replacements

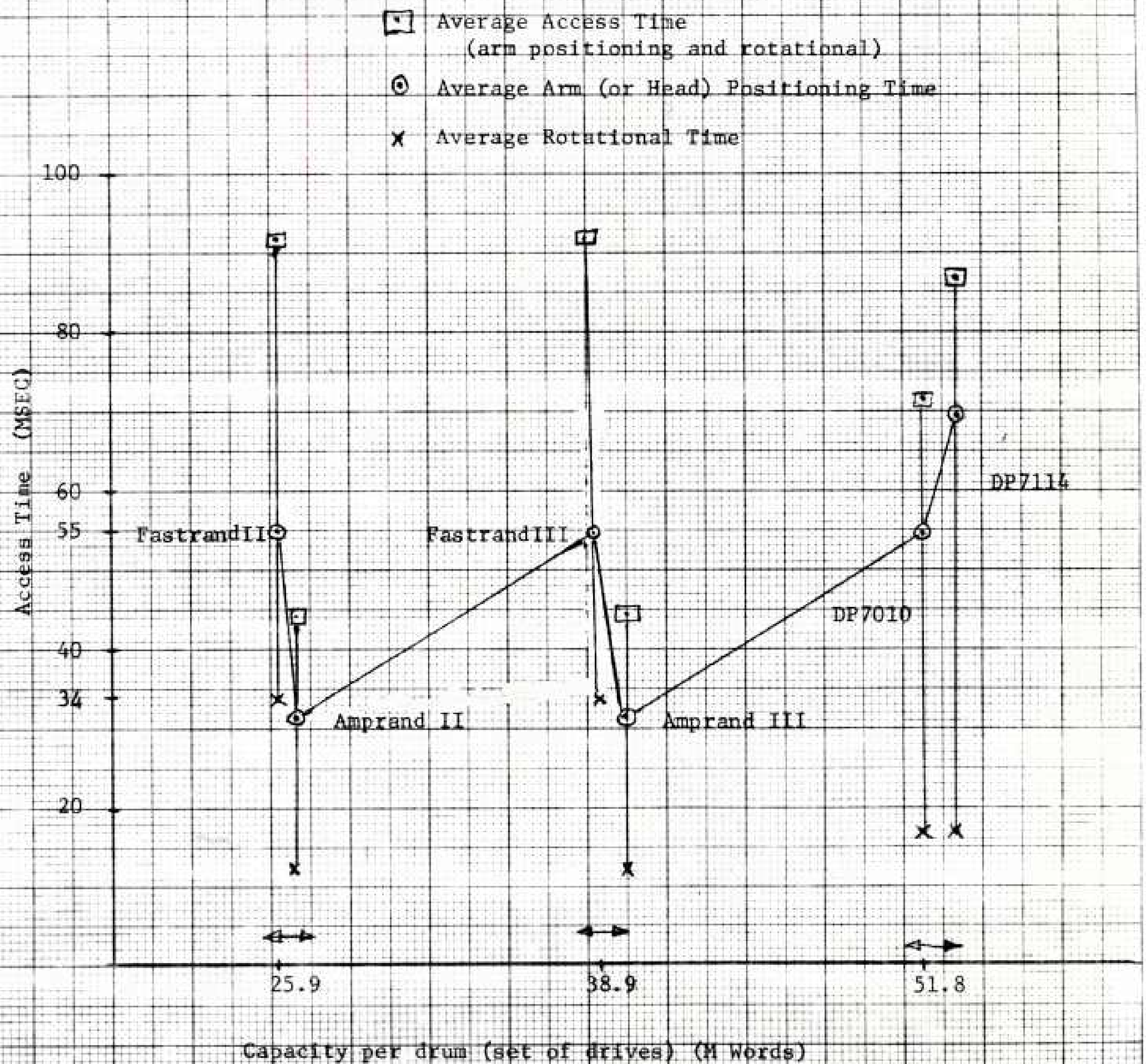


TABLE 9

RENTAL AND PURCHASE COST SUMMARY

Device	Monthly Rental Drive and Single Controller	Cost / M Words	Purchase: 8 Drives and Dual Controller	Purchase: $1,000 / M Word
Fastrand II	$4870	$188	$ 925,555	$4.47
Amprand II	3850	149	740,000*	3.58*
Calcomp 1144DS	3850+	149		
Fastrand III	6045	155	1,753,410	5.65
Amprand III	4700	121	1,402,000*	4.53*
DP 7010	2240	86.5	852,600**	2.06
DP 7114	4225	82	1,140,000++	2.75

* Ampex claims they will hold their prices 20% under Univac's.

** Dual controller (not confirmed but judged by price).

\+ Without maintenance; maintenance on order of $300/month.

++ Quoted as 35% less than Fastrand - Fastrand III assumed.

Figure 10 RENTAL COST FOR UNIVAC COMPATIBLES
RENTAL FOR 1 DRIVE AND CONTROLLER

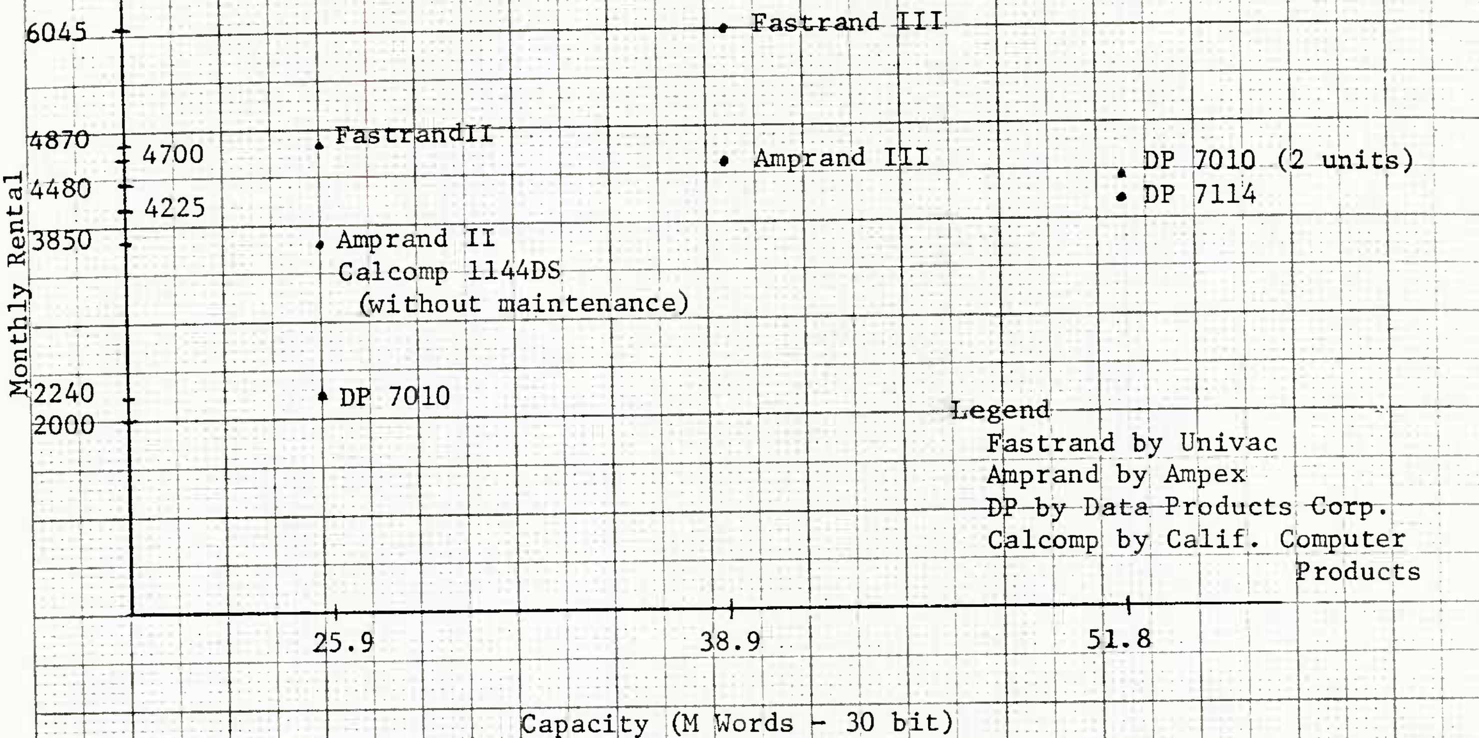
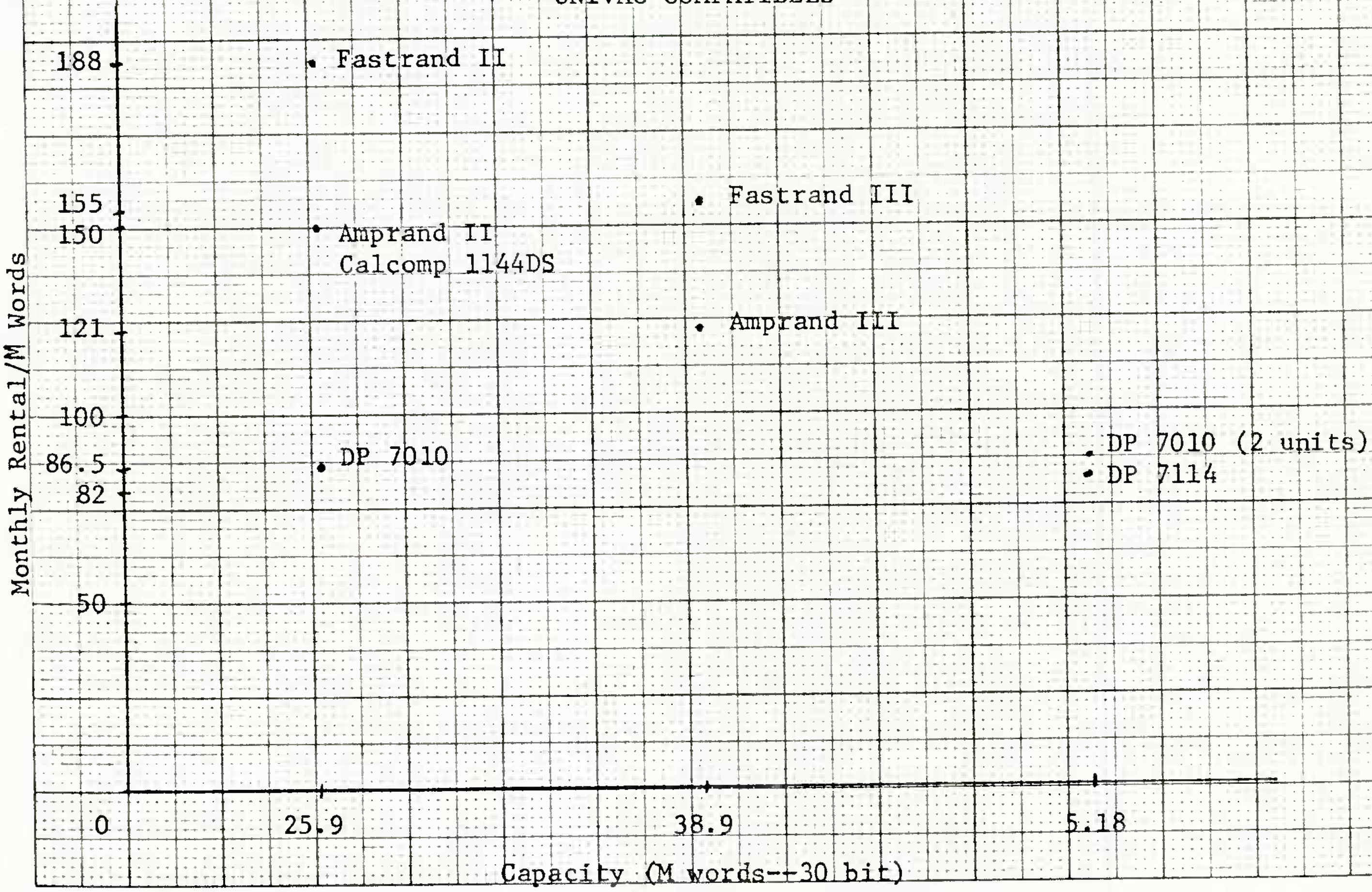


Figure 11 RENTAL COST/CAPACITY FOR UNIVAC COMPATIBLES



4. Cost/Performance Summary

Figures 12 and 13 show the relative cost per million words as a function of access time and transfer rate, respectively, concerning performance, Ampex disk drives are superior in both access time and transfer rates to the Fastrand (Ampex claims double the performance). However, Data Products' units also offer higher transfer rates, than Fastrand, and approximately the same access time, but at a much lower cost.

5. Comparison of Cost/Performance of Univac and IBM Replacements

In order to compare Univac drum replacements with IBM disk replacements, and to judge the possibility of additional Univac competition, a plot of the cost per million words versus capacity was made for Univac replacement and IBM replacement categories (Figure 14). (It should be noted that the cost data for the Univac replacements may not be very accurate since they were quoted as 20% and 35% under Univac's. See Table 9.) The only Univac compatible devices that are cost competitive with the IBM replacements are the Data Products DP7114 and DP7010. Univac has purchased the right to sell the DP7114. In all other cases there is always a possible 2 to 1 cost difference between Univac's competition and IBM's. This would seem to leave ample room for other competitors, and announcements are expected in the next 6 months.

Figure 12 RELATIVE COST VS. ACCESS TIME FOR UNIVAC COMPATIBLES

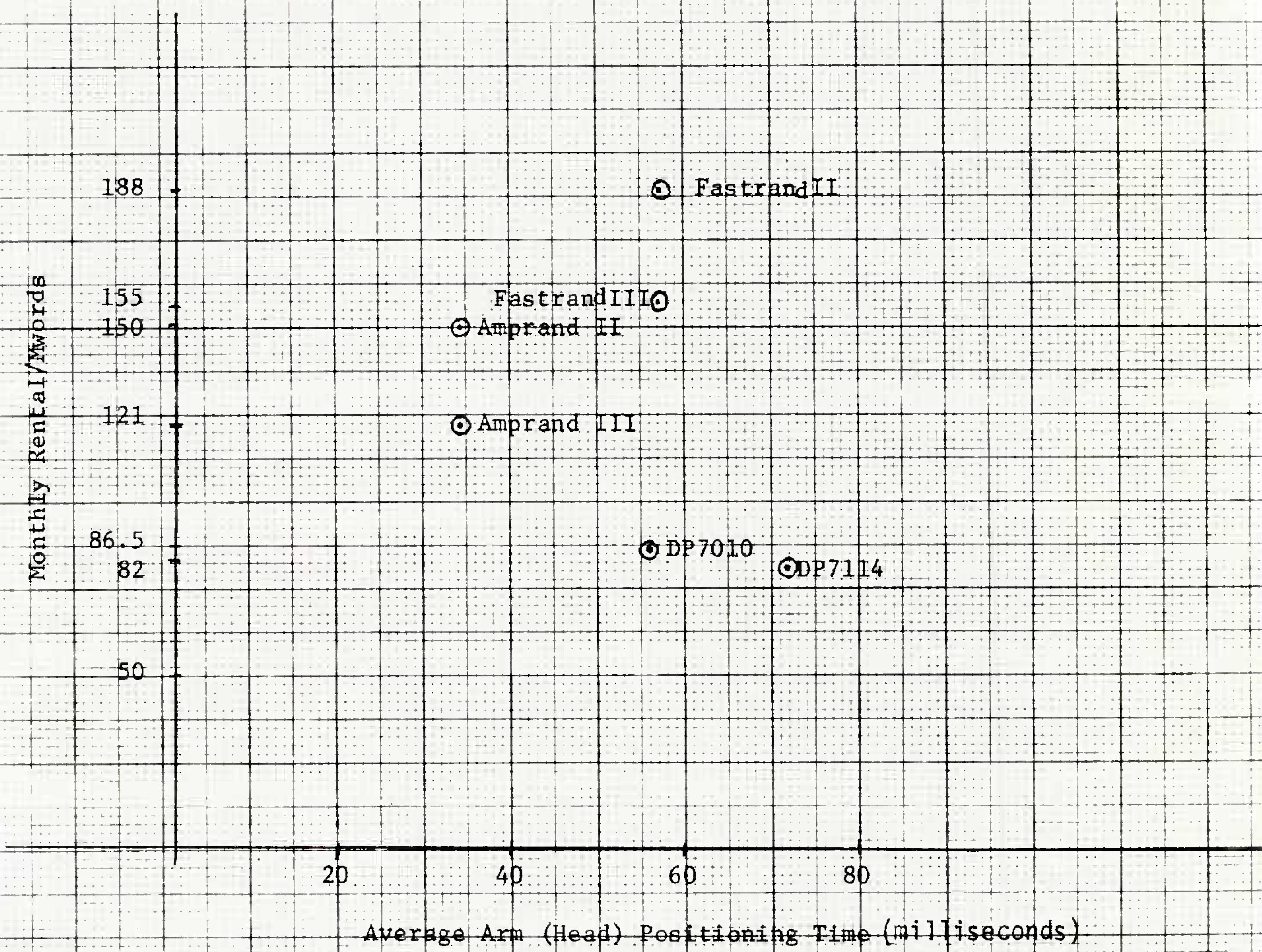


Figure 13 RELATIVE COST VS. TRANSFER RATE FOR UNIVAC COMPATIBLES

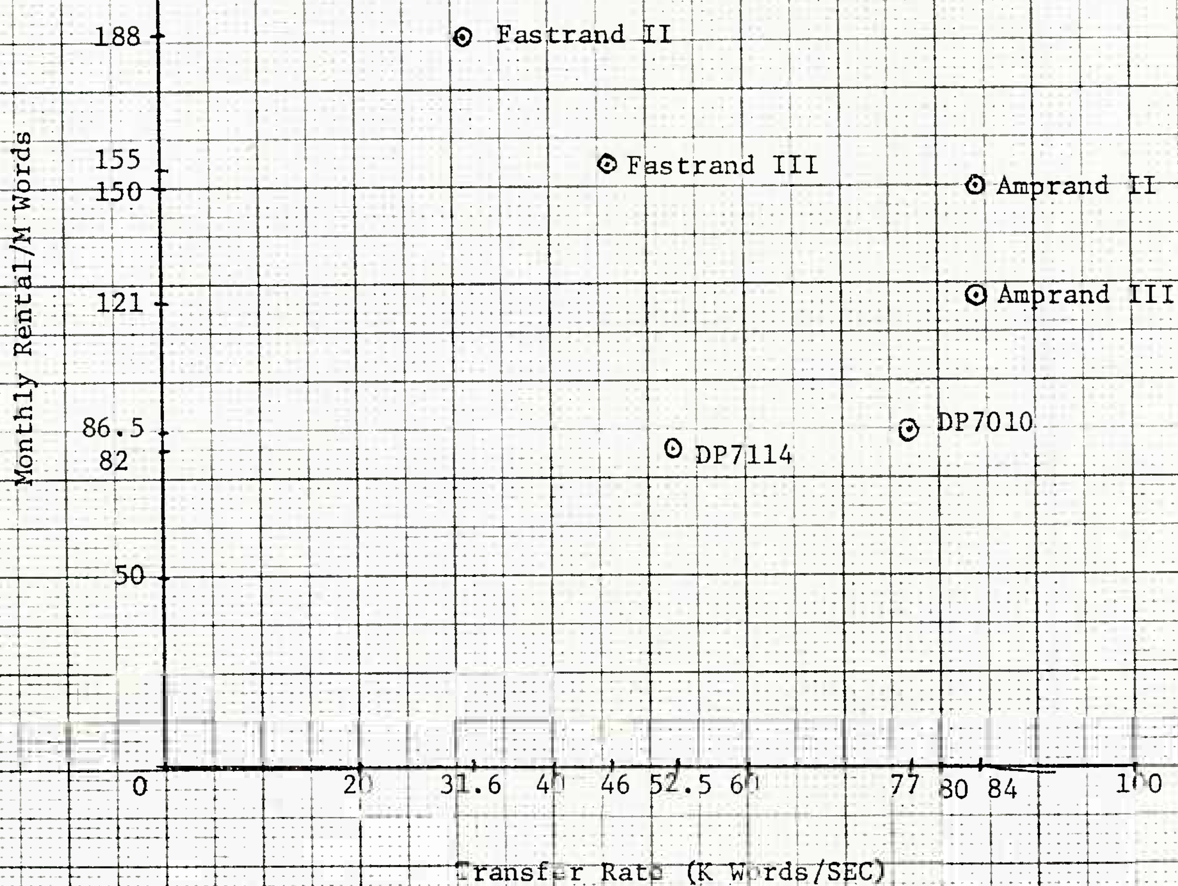
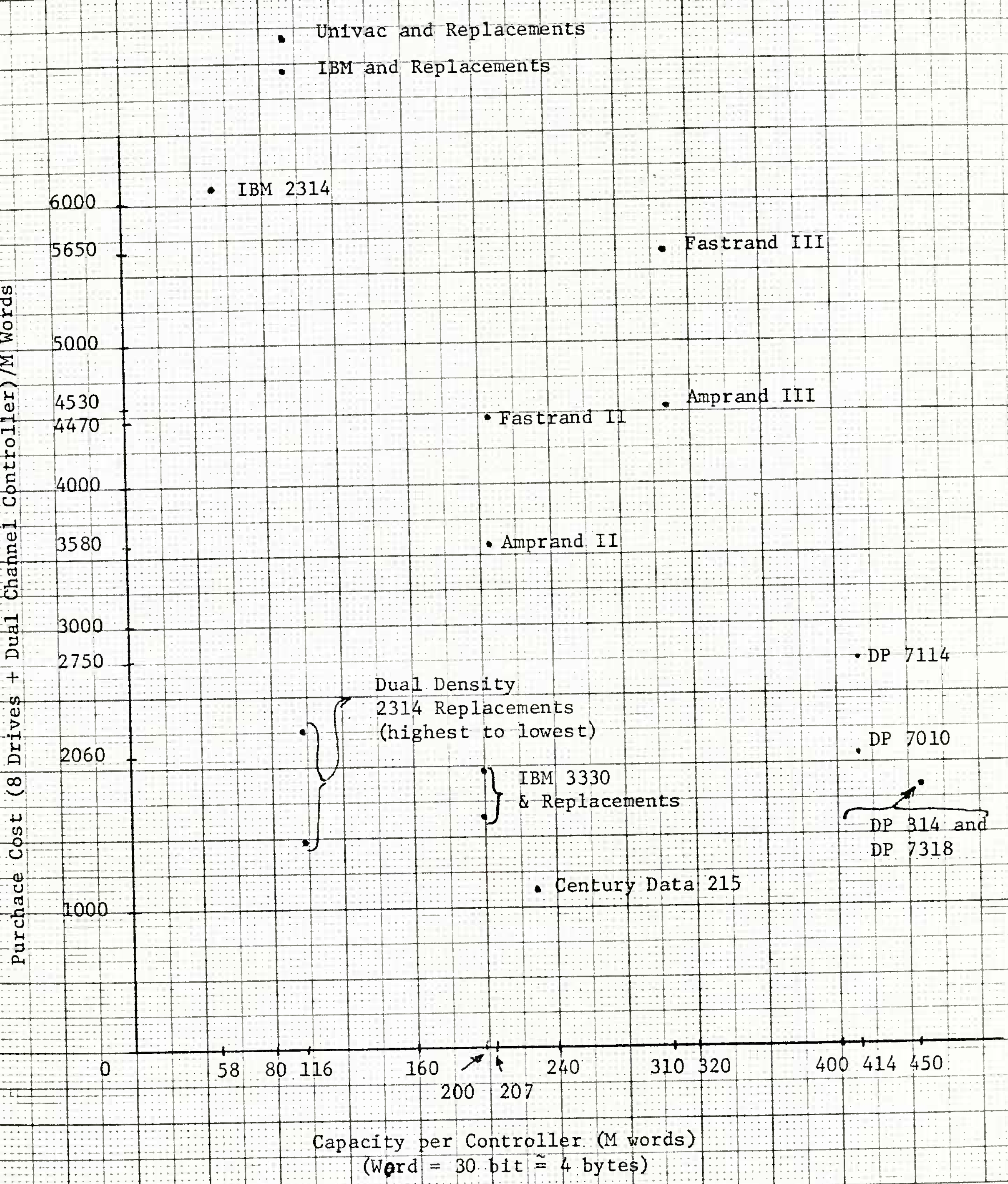


Figure 14 COST/WORD VS. CAPACITY FOR UNIVAC AND IBM REPLACEMENTS



D. Super Density Systems

This section will present another form of storage device, the massive store or trillion bit memory. These memories are not intended to replace disk or drum memories, although they may replace tape systems. They are primarily intended to provide storage for massive amounts of data requiring average access times of 1 to 20 seconds.

These super density magnetic tape devices use recording densities of 160,000 to one million bits per square inch. Even at these densities, all units use electromechanical mechanisms to access the necessary recording area for the trillion bit capacities. This is not surprising when one visualizes the amount of data in a trillion bits.

In order to judge the relative size of a trillion bits of data the following comparisons are given. A trillion bits is equivalent to:

2,900	1600 bpi fully recorded 2400' tapes, or
3,500	2314 disk packs, or
1,000	3330 disk packs, or
950	Fastrand II drums, or
250	2321 data cells (400 Mbyte Units)

Most potential users are likely to be looking for a minimum capacity system priced at $300,000 to $500,000 instead of a maximum capacity system.

Other information on these massive storage devices is shown in Table 10. Three other systems which have not been included in Table 10 are Unidara military oriented system designed by General Dynamics that uses 693,000 bits per square inch, Digipacker designed by Ardist Co. with approximately 6000 to 10,000 bpi and used by the Navy at Johnsville, and a system similar to Unicon 690 proposed by Foto-mem (119). Thus far no reliability figures and little user experience data are available for these massive memories.

In addition to reliability considerations, long access time is a problem. Before these devices are selected for primary storage medium, an analysis will have to be made to determine which applications can tolerate two orders of magnitude of degradation in access time from 30 MSEC to at least 3 seconds in order to achieve the massive capacities of the super density tape systems.

TABLE 10 SUPER DENSITY TAPE MEMORY CHARACTERISTICS

Company	Device	Capacity	Transfer Rate	Access Time	Density	Recording Technique	Compatible with and Cost	Comments & References
Data Recording Systems	Datacord ADR-2015	2 bill. bits per reel	0.3 to 19.2 mbps at 15 to 960 ips (switchable)		20,000 bpi on 4 tracks on ½" tape; 160 Kbits/sq. in.			Ref 90
Orion Products	Alpha GW	8.5 bill. bits per reel	.28 to 4.5 mpbi at 18.75 to 300 ips (switchable). 36 mbps in Aug 72		10,000 bpi on 30 tracks on 1" tape; 300 Kbits/sq. in.			Ref 90
Ampex	Terabit Memory	Min 90 bill. bits (2 drives) Max 3 tril. bits (64 drives)	3 mbps on 4 channels	2-3 sec with 4 controller & 4 drives; 40 sec max. Search speed 1000 ips.	Track density = 7500 bpi; 710K bits/sq in on 2" video tape	Video recording. Tape speed 5 ips, head speed 800 ips (across tape)	IBM 360/65 + Univac 1100 or other commericial computers. cost $500K to $3M or .0001¢/bit.	Available Mar 72. Ampex extended core storage is used as a tape buffer. Ref. 88, 93, 119
International Video	IVC-1000	Min 80 bill. bits per reel	8 mbps		1 mbits/sq in	helical scan		Ref. 80
Grumman Data Systems	Masstape with SPC-16 controller	Min 128 bill. bits Cartridge = .36 bill. bits. Max 1 trill.bits.	Tape to drum 1.2 mbpi at 12.5 ips; drum to computer 8 mbpi	Ave 6 sec, max 11 sec	8000 bpi on 16 tracks on ½" tape; 256 Kbit/sq in		IBM 360/ 50 and above. Cost $300K to $2M or .0001¢/bit. Size 16 sq ft for 128 billion bits or 2 refrigerators	Drum is used as intermediate storage. Ref. 68,117
Precision Instrument Co.	Unicon 690	Max over 1 trillion bits				Laser punched holes on tape (non-erasable)		First installed Oct. /71 at NASA Ames, and later at Amoco Production Co. Ref. 117, 119

IV. High Density Recording Technology

A. Definitions of Compatibility

Plug compatibility, or plug-to-plug compatibility, shall be evaluated in the following three aspects; hardware, software and performance. A new peripheral device is hardware compatible with another device if the new device is physically and electrically interchangeable with that device and neither the peripheral nor the equipment to which it connects requires any modification in order to effect the replacement. This requirement usually includes the ability to read the same media without rerecording or other conversion. A new peripheral device is software compatible with another device if the device functions properly within the computer system without any modification or changes to the operating system, utility and diagnostic programs, input/output driver programs, and user programs. This implies that the peripheral will accept all standard function codes and formats and respond will all the standard control responses and formats at the appropriate logic levels and timing intervals. A new peripheral devices is performance compatible with another device if the new device has performance characteristics that will not degrade the computer system operating characteristics in any manner. (1) This definition allows equal or better performance. In order to be plug compatible a new device must satisfy all three compatibility conditions.

If a device is not compatible in all three aspects the discrepancies and probably corrective action will be discussed in the text.

A tape transport is said to be IBM compatible if any tape recorded on that transport can be read on a similar type IBM transport, and if tapes recorded on the IBM transport can be read on the transport under consideration. What this is really saying is that compatibility will permit completely free interchangeability of tapes between transports regardless of who manufactured them.

IBM compatible should not be confused with IBM plug compatible. The first is limited to the interchangeability of tapes; the second relates to the interchangeability of both tapes (or disk packs) and the transport system--transports, controllers, interfacing.

B. Standard Recording Techniques

The common magnetic recording techniques are non-return-to-zero (NRZ), non-return-to-zero-mark or non-return-to-zero inverted (NRZ1), and the bi-phase or phase-encoding (PE). NRZ and NRZ1 both use saturation recording, i.e., each recorded pulse saturates the oxide on the tape completely and no part of the tape or disk is partially recorded or unrecorded. In standard NRZ, each recording of a change from a zero to a one or vice-versa is indicated by a full flux transition. In this system a string of ones will show no transitions, nor will a string of zeros. However, a transition will take place each time a one follows a zero or a zero follows a one. On the other hand, the NRZ1 has a flux transition for each one, with no transition for a zero. This method is efficient, relatively error free, capable of densities up to 1000 bpi (with standard decording schemes; see below) and represents the bulk of present day digital recordings used on computers. Both NRZ and NRZ1 encoding share one common problem which affects data accuracy. In NRZ a long string of zeros or ones, and in NRZ1 a long string of zeros, result in signal pulses of extremely long duration. This means that the detection circuit must have a wide band-width in order to accept very low frequencies as well as high frequencies (when successive bits alternate) which results in high noise levels. Another disadvantage is that computer recording formats must ensure that there is one pulse change on one of the 7 or 9 tracks for every bit cell in order to synchronize the receiver with the recorded pulses.

C. High-Density Recording Techniques

1. NRZ Recording at 3000 bpi

Schmitt and Melsa have presented two methods of obtaining low error rates with NRZ encoding for densities up to 3000 bpi. They stated that for densities up to 1000 bpi a simple integrate and dump detection (reading) scheme would produce less than one error in 10^9 bits (with signal-to-noise ratios of 16 decibels), but for higher densities a double sided intersymbol interference detector or a maximum a posteriori processor could be used to achieve the same error rate of one error in one billion bits with non-return-to-zero coding. They also showed that error rates for these two detectors were minimum for 2400 to 3000 bpi and quite usable up to 5000 bpi. They developed formulae for calculating error rates and verified their theoretical results using a magnetic disk (108).

2. Phase-Encoding Saturated Recording

In order to overcome the deficiencies of NRZ and NRZ1 encoding discussed above, another saturation recording technique provides at least one flux transition for each bit cell. Various codes called phase-encoding, bi-phase, Manchester, split-frequency, Harvard, etc., have been used for recording on tape. Since both phase-encoding and bi-phase are used extensively and provide high reliability, they will be discussed in more detail.

The phase-encoding technique represents a one as being a positive pulse and a zero as being a negative pulse. Since a lack of data causes no pulse to be generated, this method allows a positive distinction to be made between a "no bit" and a zero bit, which could not be done with NRZ1 recording. Also this technique requires a phase reversal to the "no bit" condition after each bit so that sequenial ones or zeros can be recorded. Thus 1600 bpi phase-encoded tapes actually have 3200 phase reversal compared to 800 phase reversals per inch with 800 bpi NRZ1 tapes.

The positive identification of a missing bit, combined with a vertical parity check, permits the correction of single bit errors without interrupting the data input. One of the significant ways in which phase-encoding differs from NRZ1 is in the handling of vertical redundancy checking after writing. The NRZ1 drives perform a read-after-write check to determine if parity is correct, while the phase-encoding units perform both envelop checking and multiple-track error checking to detect weak signals on any track and abnormal changes in data rate while writing, respectively. During reading, multiple-track error checking procedures are used to detect weak signals from two or more tracks, while single-track error correction is made by searching for the absence of a flux reversal in any data frame in any one track and then automatically regenerating the missing bit (110).

One disadvantage which is a concern to some users is that the faster drives may cause more strain of the magnetic tape which may lead to premature tape failure due to tape stretching, but no sta-

tistics are available.

3. Bi-Phase Saturated Recording

The bi-phase saturated recording technique is very similar to the phase-encoding and share many of the same advantages over NRZ recording. Bi-phase recording uses two flux changes per bit cell to represent a one and one flux change to represent a zero. The distinguishing feature of bi-phase technique is that only two fundamental frequencies are present: the frequency f for zero and 2f for one. With NRZ1 recording the frequency spectrum is much greater because a string of zeros can result in an output signal approaching dc, while a string of ones will result in a high frequency signal dependent of recording density and tape speed. The narrower bandwidth achieved in bi-phase recording results in improved signal-to-noise ratios. Narrow bandwidth also permits head response to be tailored for maximum output at the two frequencies, and steep waveforms with sharp zero crossings are obtained. These are easily detected and reduce the error rate especially at low signal levels.

In practical systems, the bi-phase recording technique results in double the packing density at the same bit accuracy when compared to NRZ1 recording. Saturation bi-phase recorders can achieve packing densities up to 3500 bpi with error rates below 1 in 10^6 bits (107). They require more complex electronic circuits, not only for the recording and reproducing process but also for coding and decoding the basic binary data.

New techniques of nonsaturation recording have recently been developed for higher capacity, higher transfer rate, and with better data accuracy. These methods are expected to supplement rather than supplant the older methods.

4. Bi-Phase Nonsaturation Recording

In saturation recording, head current is sufficient to completely magnetize the tape to positive or negative polarity. Carrier modulated recording, on the other hand, depends upon preservation of the amplitude, frequency, and phase angle of the signal for its information content and does not need to saturate the tape. Bi-phase information may be recorded by either saturation or carrier modulation techniques. For standard recording tapes, bit density in saturation recording is limited by the oxide thickness. With a 0.5 mil thick oxide, density is limited to approximately 850 bpi, while with 0.21 mil thick tape approximately 3,000 bpi is possible. Nonsaturation recording is not limited in packing density by tape thickness, and by applying these techniques to bi-phase digital information, certain advantages are obtained over conventional saturation techniques.

To implement the nonsaturation technique, incoming bi-phase encoded signal is filtered to remove its harmonic content and correct its phase. The corrected, filtered signal is then mixed with a high frequency bias signal, approximately 8 to 10 times the highest fundamen-

tal data frequency, and fed through the direct record amplifier to the tape heads. A flat-flux, low-distortion, high-packing density recording is made.

Reproduction takes place with the head output equalized across the desired bandwidth with a low distortion pre-amplifier. This signal is fed to a bandpass filter which limits the passband for improved signal-to-noise and equalizes the signal phase to retain the integrity of the recorded signal. A hard limiter, as conventionally utilized in wideband FM discriminators, detects the zero crossings, and the signal is restored to its original state.

With a dynamic range of approximately 60 dB, minimum susceptibility to dropouts is achieved, and packing densities of up to 16,000 bpi, with a bit error rate of 1 in 10^8, are attained (107).

In recorders required to operate under environmental stresses for long unattended periods, a lower bit packing density becomes desirable. A density on the order of 7,000 bits per inch offers ample margin for good reliability and data accuracy.

A demonstration of the bi-phase nonsaturation recording for high density recording was made recently by Kinelogic Corp. of Pasadena, California. Using recently developed electronic components employing standard components, they were able to record data at 6000 bpi at 30 ips, with an error rate of less than 1 in 10^8. Using the same electronics and operating at 15 ips, a conventional recorder was able to write and read serial data 12,000 bpi, with an error rate of 1 in 10^6. Standard instrumentation tape and heads were used for this demonstration. (107).

D. Five Methods of Achieving Double Density on Disks

The ability of a 2316 disk pack to store 58 million bytes instead of 29 million has been referred to as double density, double capacity and dual-cylinder density. This increase in storage capacity requires a physical change in the data recording equipment, specifically the disk drive and possibly the controller, but no change in the 2316 disk pack. Of prime concern in the double density environment is the ability to execute existing system and application software without modification.

The distinguishing features of the five basic physical methods for doubling the capacity of a 2316 disk pack are summarized in Table 11
The first method is accomplished by reducing the rotational speed of the disk by one half, thereby allowing for doubling the data recording density. This method requires software modification to existing operating systems because twice as much information is written on each disk track, i.e., a physical record is twice as long. The major problem with this method is that reducing the rotational speed to 1200 rpm doubles the average latency time to 25 MSEC. Before deciding to use a drive of this type, a search monitoring program should be used to determine the effect of doubling the average rotational delay and potentially doubling the search time. The Memorex 3665 uses this method.

The second method does not alter the rotational speed of the disk, but it does double the recording density. This method increases the I/O transfer rate to 624 KBYTES/SEC and is therefore limited to IBM 360/65 systems and above. None of the recorded compatible disk drives use this method.

The remaining three methods use 406 cylinders and double the tracks per inch, but use different organizations. The third method organizes the disk pack as having twice the number of cylinders. The data management routines in the system software must be modified to use the space available; i.e. space availability is determined by examining the VTOC (volume table of contents) and use a base of 203 cylinders for necessary calculations. Other modifications are required to access methods and I/O supervision. Telex 6330 uses this method.

The fourth method uses 406 cylinders also, but divides them into two logical halves which are addressed as two separate disk packs. The major advantage of this method is that no software modifications are required. The major disadvantage of this method is that 200 cylinders must be transfersed in order to access the other logical unit. From an examination of the seek timing graph, about 80% of the arm positioning time is expended in transversing the first 200 cylinders, especially if the VTOC remain on cylinder 0 of both units. This time can be reduced if the VTOC of the first logical unit is on cylinder 199 and the VTOC of the second logical unit is on its cylinder 0. The effect of having nonstandard VTOC's must now be evaluated to determine the extent of system and operational repercussions. Control Data 23142 and Marshall Data Systems 2900 are examples of this method.

TABLE 11

SUMMARY OF DUAL DENSITY METHODS

	RPM	Transfer Rate (BYTES/SEC)	Density	No. of Cylinders	Distinguishing Features
Method 1	1200	312	double bpi	203	Latency time is doubled.
Method 2	2400	624	double bpi	203	Double transfer rate; restricted to 360/65 and above.
Method 3	2400	312	double tpi	406	Organized as disk packs with 406 cylinders each.
Method 4	2400	312	double tpi	406	Each 406 cylinders are split into two logical halves, i.e. they are addressed as two disk packs.
Method 5	2400	312	double tpi	406	Same as method 4 except cylinders from the two logical halves are interleaved.

The fifth method also uses 406 cylinders divided into two logical units but in this method the cylinders are interleaved rather that split into two continguous segments. As with the previous method, no software modifications are required. By interleaving the cylinders, data sets can be physically placed for optimum access. If the centers of activity of two data sets are the same, then this method will produce equal or better access time compared to two separate disk drives; and very little, if any, system degradation will occur. The fifth method is the only one that can read disk packs that were written on single density drives. This is a very powerful feature for file conversion and provides some compatibility. Calcomp CD22 uses this method for achieving double density disks.

Although most of the double density devices in this report use the fourth or fifth method, there is insufficient information in the literature to distinguish between the two methods for the other devices.

E. Drive Technology and Mechanization

The significant technical advances in the design of tape drives and disk drives are shown in Tables 12 and 13, respectively, along with the advantages of each feature. These new features often give the high density compatible devices a performance advantage over the replaced OEM devices.

TABLE 12

Tape Drive Features

Old (poor)	New (better)	Advantages
NRZ recording	Phase encoding	Higher density, lower error rates
Pinch roller drive presses tape against a rotating capstan	Low inertia motor starts and stops to control tape movement	Does not press dirt into tapes, more gentle tape handling and more repeatable start-stop performance (on IBM 2420)
Tape speed depends on capstan speed	Optical tachometers to sense tape speed	Senses small variations in tape speed and generates corrective signals.
Does not apply	Incremental tape drives use stepping motors and low inertia motors	Can record one character at a time and remain stationary waiting for the next one.
Reel connected to motor via clutches, mechanical relays, vacuum switches, and thyratron tubes	Reel drive motor directly coupled to tape reel with semiconductor controls	Increased reliability, reduced wear and reduced size.
Does not apply	Long-life recording heads	Shows negligible wear after 2000 hours of operation.
Constant rpm rewind	Rewind speed controlled by servo-type system	Constant tape speed instead of variable and very high tape speed.
Tape guided by roller	Tape guided by vacuum column control during rewind	Near constant tension and edge guidance
Fixed Heads	Heads moved out of way during rewind	Reduces tape wear
Each tape drive connected to the control unit serially through its neighboring drive	Drives connected by radial inferface technique	Any tape drive can be taken out of operation for maintenance without changing cables or interrupting the control unit or other tape drives.
Analog to digital conversion in control unit	Analog to digital conversion in tape drive itself	Reduces error due to electrical noise

TABLE 13

Disk Drive Features

Old (poor)	New (better)	Advantages
Hydraulic activated servo	Voice coil activated	Low access time, simplier and lower cost.
Electro-mechanical detenting to check position of head	Electronic detenting	Higher reliability; operates faster, silently and only errors are in the transducer.
Mechanical fixed head positioning	Head to surface positioning by flying head design	Lower distance between head and disk surface. Head is supported 60 to 200 microinches above surface by the airstream between head and surface.
No rotational position sensors on disks	Rotational position of the disk is sent back to computer	Allows data to be presorted so that the record nearest the head can be requested first. Available on IBM 3330 but no manufacturer supplied capability on 370.

V. Conclusions

Based on the information which was provided in the previous sections, conclusions appear below segregated by type of peripheral unit. These conclusions are based on published design specifications and do not necessarily reflect differences in actual performance and cost-performance of installed units.

A. Magnetic Tape Units

The magnetic tape units which were surveyed consist of units compatible with the IBM 2401-5, 2401-6, 2420-5, 2420-7, 3420-3, 3420-5, and 3420-7.

1. It was found that there are no significant performance differences within each compatible group.

2. In addition, there is a great deal of performance compatibility across compatible groups, except for tape speed. Thus, transfer rate is the only throughput factor which differs significantly among groups.

3. Compatible unit prices are lower than IBM prices in all groups.

4. The cost-performance of the IBM 3420 group is superior to the cost performance of the IBM 2401 group and the IBM 2420 group.

5. Except for maintenance service, users appear satisfied with their tape unit replacements.

B. Disc Units

1. Dual Density IBM 2314 Replacements (58 MBYTES per drive)

   Compatible equipment is superior to the IBM 2314 with respect to access time (one-half) and capacity (double). Compatible units are three to five times better than the IBM 2314 on a price per BYTE basis and, in general, are less expensive than the IBM units.

2. Higher Density IBM 2314 Replacements (116 or 232 MBYTES per drive)

   Compatible equipment has a slight advantage over the IBM 2314 with respect to access time and a capacity 4 to 8 times greater. The cost per BYTE of compatible equipment is 3 to 5 times lower than the IBM 2314 cost per BYTE. The price of compatible units varies from 1.2 to 7 times the IBM 2314 prices, depending upon the capacity of the compatible unit.

3. IBM 3330 Replacements (100 MBYTES per drive)

   In contrast to the first two disc drive groups, compatible units do not provide performance and performance-cost advantages with respect to the IBM 3330. There are no significant differences in access time, capacity or cost per BYTE among the various units. The IBM 3330 is about in the middle of the price range of the compatible units.

4. Comparison Across Replacement Groups

When a comparison is made across replacement groups the following patterns emerge:

a. Access Time
Access time is ranked below in order of shortest to longest access time.

- IBM 3330 Replacement, IBM 3330 and Dual Density IBM 2314 Replacements.
- Higher Density IBM 2314 Replacements
- IBM 2314

b. Capacity
Storage capacity is ranked below in order of largest to smallest capacity.

- Higher Density IBM 2314 Replacements
- IBM 3330 Replacements and IBM 3330
- Dual Density IBM 2314 Replacements
- IBM 2314

c. Cost
Cost is ranked below in order of least expensive to most expensive.

- Dual Density IBM 2314 Replacements
- IBM 2314
- Higher Density IBM 2314 Replacements (116 MBYTES per drive)
- IBM 3330 Replacements and IBM 3330
- Higher Density IBM 2314 Replacements (232 MBYTES per drive)

d. Cost/BYTE
Cost per BYTE is ranked below in order of lowest to highest cost per BYTE.

- Higher Density IBM 2314 Replacements (116 MBYTES per drive)
- Dual Density IBM 2314 Replacements, IBM 3330 Replacements, IBM 3330 and Higher Density IBM 2314 Replacements (232 MBYTES per drive)
- IBM 2314

5. Navy users of IBM compatible disc units report many difficulties with respect to equipment reliability. In general, there was no increase in throughput or decrease in response time noted.

C. Drum Units

The drum units which were surveyed, consist of units compatible with the Univac Fastrand II and Fastrand III drums.

1. Compatible unit performance is superior to the Univac Fastrand II and Fastrand III with respect to cost per word and transfer rate. The cost of compatible units is also lower.

2. The storage capacity of compatible units equals or exceeds the storage capacity of Fastrand units.

3. There is no significant difference in access time among the units.

4. In general, IBM disc compatible cost per word is lower than Univac drum compatible cost per word. Also, the IBM disc compatibles have shorter access times and faster transfer rates than the Univac drum compatibles. The storage capacity of Higher Density IBM 2314 units is about the same as the Univac drum compatibles capacity. Based on these comparisons, the IBM disc compatibles appear to provide superior cost/performance in relation to Univac drum compatibles.

D. As evidenced by the ADPESO contracts and other user installations, high density units are readily available; they have been installed in large numbers; but the extent of realized improvements in performance, true cost reductions and increased reliability is in doubt due to the lack of quantitative data from user installations. In order to overcome this difficulty, it is recommended that during the next phase an opportunity be provided to visit selected user installations in an attempt to obtain definitive performance and reliability data.

VI. Appendix

A. Installations Included in User Survey of Plug Compatible Hardware

Installation	Configuration	Applications
BUPERS, Washington, D. C.	IBM 360/65 1 million bytes core 32 Disc Drives 21 Tape Drives 2 Card Read/Punch 3 Printers O/S-MVT HASP	Personnel Record Processing, Personnel Accounting, Navy Appropriations
Personnel Accounting Machine Installation, Bainbridge, MD	IBM 360/40 128 K core 16 Disc Drives 6 Tape Drives 1 Card Read/Punch O/S-PCP	Personnel Accounting
Marine Corps Base, Camp Lejune, N.C.	IBM 360/50 512 K core 18 Disc Drives 12 Tape Drives 2 Card Read/Punch 2 Printers 4 User Terminals	Personnel, Supply, Finance, Project Prime
Navy Regional Finance Center Cleveland, Ohio	IBM 360/50 256 K core 8 Disc Drives 9 Tape Drives 1 Card Read/Punch 1 Printer O/S-MFT	Payroll - Retired, Reserve Jumps, Allotments
Naval Supply Center, San Diego, CA	IBM 1410 6 Tape Drives 1 Card Read/Punch 1 Printer COPE	Inventory - UDAPS, Accounting, Payroll, Stores, Allotment
Navy Astronautics Group Point Mugu, CA	IBM 7094 32 K core 1 Drum 1 Printer 1 Card Read/Punch IBM 360/40 128 K core 5 Disc Drives 2 Tape Drives 1 Card Read/Punch 1 Printer	Scientific - Satellite Orbital Predicting

Navy Regional Finance Center San Diego, CA	IBM 360/30 65 K core 6 Tape Drives 3 Disc Drives 1 Card Read/Punch 1 Printer DOS	Accounting, Payroll, Finance
Navy Electronics Laboratory Center San Diego, CA	IBM 360/50 512 K core 1 million bytes bulk core 8 Disc Drives 9 Tape Drives Remote Batch Remote Terminals O/S-MVT	Time sharing, Remote batch, Scientific - Data Reduction, Strategic Systems, Management Applications
Naval Construction Battalion, Port Hueneme, CA	IBM 360-50 512 K core 27 Disc Drives 15 Tape Drives 2 Card Read/Punch 5 Printers User Terminals O/S-MVT	Financial Management Military Construction CEL Support, Payroll, Inventory, Scientific Simulations
Pacific Missile Range Point Mugu, CA	PDP-9 2 High Speed Digitalizers 5 Tape Drives 1 Card Read/Punch 1 Printer	Scientific - Post Flight Processing, Telemetry Data Digitalizing, Radar Recording, Spectrum Analysis
Marine Corps Base Camp Pendleton, CA	IBM 360/50 512 K core 18 Disc Drives 9 Tape Drives 2 Card Read/Punch 2 Printers User Terminals O/S-MFT	Personnel, Manpower Management, Supply, Finance, Warehousing, Project Prime
Marine Corps Supply Center Barstow, CA	IBM 360/40 382 K core 16 Disc Drives 8 Tape Drives 2 Card Read/Punch 3 Printers O/S MFT DOS	Supply, Inventory, Requisitions, Shipping, Payroll

Installation	Configuration	Applications
Naval Weapons Center China Lake, CA	Univac 1108 130 K core 8 Disc Drives 16 Tape Drives 1 Printer 1 Card Reader 1 Communications Terminal Module Controller Univac 9300 1 Card Reader 1 Card Punch 1 Paper Tape Read/Punch User Terminals Exec 8	Scientific, Engineering, Business

B. REFERENCE LIST

1. Frost, Cecil R. - IBM Plug-to-Plug Peripheral Devices <u>Datamation</u>, 15 OCT 1970, p. 24.

2. Murphy, John A. - Magnetic Tape Systems, <u>Modern Data</u>, SEPT 1971, p. 44.

3. Ampex Corp. Advertisement, <u>Datamation</u>, 15 NOV 1970, p. 80.

4. Disk and Drum Drives - Part 1, <u>Modern Data</u>, JAN 71, p. 58.

5. Applied Magnetics Corporation Advertisement, <u>Datamation</u>, 1 SEPT 1970, p. 77.

6. Bryant Computer Products Advertisement, <u>Data Processing</u>, JULY 1970.

7. Bryant Computer Products Advertisement, <u>Data Processing</u>, SEPT 1970, p. 169.

8. Bryant Computer Products Advertisement, <u>Datamation</u>, JUNE 1970.

9. Burroughs - Compatible Disc Drive Debuts, <u>Datamation</u>, APR 1970, p. 218.

10. Caelus Memories Advertisement, <u>Datamation</u>, 15 NOV '71 p. 79.

11. California Computer Products Advertisement, <u>Datamation</u>, 1 AUG 1971, p. 49.

12. California Computer Products Advertisement, <u>Datamation</u>, 1 NOV 1970, p. 30.

13. Century Data Systems Advertisement, <u>Datamation</u>, 15 APR 1971, p. 34.

14. Control Data Corporation Advertisement, <u>Datamation</u>, 1 JUNE 1971, p. 84.

15. Control Data Corporation Advertisement, <u>Datamation</u>, 1 DEC 1971.

16. Data Processing Financial & General Corporation, <u>Datamation</u>, 15 OCT 70, p. 114.

17. Data Products Advertisement, <u>Datamation</u>, 1 JUNE 1971, p. 59.

18. Product Spotlight, Datamation, 15 AUG 70, p. 87.

19. Information Storage Systems Advertisement, Datamation, 15 AUG 71.

20. Marshal Data Systems Advertisement, Datamation, APR 70, p. 255.

21. Telex Advertisement, Datamation, 1 OCT 71, p. 38.

22. Telex Advertisement, Peripherals Weekly, 3 SEPT 70.

23. Bucode Inc. Advertisement, Peripherals Weekly, 1 OCT 70, p. 11.

24. California Computer Products Advertisement, Peripherals Weekly, 1 OCT 70, p. 15.

25. Telex Computer Products Advertisement, Datamation, 15 NOV 71.

26. Texas Instruments Inc., Datamation, 15 APR 71.

27. Telex, Potter, Calcomp Article, Peripherals Weekly, 7 JAN 71.

28. Bucode Inc. Advertisement, Peripherals Weekly, 28 JAN 71.

29. Information Storage Systems Inc. Advertisement, Peripherals Weekly, 18 MAR 71.

30. Potter Instrument Co. Advertisement, Peripherals Weekly, 1 APR 71.

31. Telex Advertisement, Computer Design, JAN 70.

32. Telex Advertisement, Peripherals Weekly, 23 DEC 71.

33. Potter Instrument Advertisement, Peripherals Weekly, 18 NOV 71.

34. Data Processing Financial & General Corp. Advertisement, Computerworld, 23 AUG 70, p. 9.

35. Ampex Article, Computerworld, 28 OCT 70, p. 21.

36. Ampex Article, Computerworld, 13 JAN 71, p. 51.

37. Calcomp Article, Computerworld, 20 JAN 71, p. 1.

38. Telex Article, Computerworld, 20 JAN 71, p. 29.

39. Century Data Systems Advertisement, Computerworld, 10 MAR 71, p. 13.

40. Texas Instruments Article, Computerworld, 10 MAR 71, p. 21.

41. Bryant Offers Plug-to-Plug Replacements for IBM 2314 - Don Leavitt, Computerworld, 10 MAR 71, p. 21.

42. Potter Produces Plug-to-Plug Replacement for IBM 3420/3803, Computerworld, 7 APR 71, p. 15.

43. Marshall Doubles Disk Data Capacity - Frank Piasta, Computerworld, 14 APR 71, p. 17.

44. ISS Disk Drive Has 58 Mbyte Capacity, Computerworld, 14 APR 1971, p. 30.

45 Marshall Data Systems Advertisement, Computerworld, 21 APR 1971, p. 29.

46. 1971 SJCC Opens in a 'Concerned Atmosphere' - Ed. Bride, Computerworld, 19 MAY 71, p. 1.

47. Tracor Data Systems Advertisement, Computer Decisions, FEB 1971.

48. Tracor Data Systems Advertisement, Business Automation, 1 FEB 71, 1 APR 71, and 1 MAY 71.

49. Information Storage Systems Abstract, Computer Decisions, APR 1971.

50. Tape System Can Replace IBM 3420's, Computer Decisions, SEPT 71.

51. Tape System for 360's, 370's Cost Users 20% Less, Computer Decisions, AUG 71.

52. California Computer Products Advertisement, Computer Automation, 1 MAY 71, p. 38.

53. Disk System is Compatible with IBM's New Units, Century Data Systems, Computer Decisions, OCT 71.

54. Marshall Data Systems Advertisement, Computer Automation, SEPT 71.

55. Wang Computer Products Advertisement, Business Automation, OCT 71.

77. Univac Peripherials, Computer Industry Annual, 1967-68.

78. Computer Price Guide for Time Brokers Inc. (TBI), Winter 72 (Quotes list and used prices).

79. Computer Specs, American Data Processing Inc., 1969, 19830 Mack Avenue, Detroit, Michigan 48236.

80. Univac Offers DP Disk, Computerworld, 19 JAN 72.

81. Memorex Offers 3330 Replacement, Computerworld, 20 OCT 71.

82. CDC Adds 2314 Double Density Disk, Computerworld, 29 SEPT 71.

83. More Double-density Disks Available, Computerworld, 22 SEPT 1971, p. 19.

84. Telex Advertisement, Computerworld, 8 SEPT 71.

85. Calcomp Advertisement, Computerworld, 8 SEPT 71.

86. Two Plug Compatible Disk Drives, Data Products News, JULY 71.

87. Century Data Systems, Data Products News, JUNE 71.

88. Radically New Computer Memory System, Data Products News, MAY 71.

89. Storage Technology Corporation Brochure, ST 3400/3800-111, Magnetic Tape Subsystem.

90. Departures From IBM Compatible Tape Formats, etc., Modern Data, AUG 71, p. 55.

91. Do You Need to More than Double 2314 Capacity, (Taylor's article) Computerworld, 15 SEPT 71, p. 11.

92. Auerbach, OCT 71, pp. 66-79.

93. Drives Store Three Trillion Bits On-line, Computerworld, 21 APR 71, p. 1.

94. Five Double Density Disk Drive Methods Outlined, 12 JAN 72, Computerworld, p. 41.

95. STC Offers Real Alternate, Not Just "Plug" Economy Reprint of Taylor Report, Computerworld, (Assessment of Storage Technology Corp's new controller and diagnostic routines.)

96. Independents Improve on 3420's (STC and Ampex), Computerworld, 10 NOV 71.

97. Contract N66032-71-C-0004, Ampex Corporation, Department of the Navy, Automatic Data Processing Equipment Selection Office, Washington, D. C., 25 AUG 70.

98. Contract N66032-71-C-0002, Potter Instrument Company, Inc., Department of the Navy, Automatic Data Processing Equipment Selection Office, Washington, D. C., 25 AUG 70.

99. Contract N66032-71-C-0005, Midwestern Instruments, Inc., Telex Computer Products Group, Department of the Navy, Automatic Data Processing Equipment Selection Office, Washington, D. C., 25 AUG 70.

100. Contract N66032-71-C-0001, Memorex Corporation, Memorex Equipment Group, Department of the Navy, Automatic Data Processing Equipment Selection Office, Washington, D. C., 25 AUG 70.

101. Contract N66032-71-C-0003, California Computer Products, Inc., Department of the Navy, Automatic Data Processing Equipment Selection Office, Washington, D. C., 25 AUG 70.

102. ADPESO's Peripheral Replacement Program, Weihrich, Fred W., Navy Supply Corps Newsletter, DEC 1970, pp. 38-39.

103. How Navy Does, and User Can, Buy Peripherals Independently, Pantages, Angelino, Datamation, APR 15, 1971, p. 42.

104. Independent Disc System User Is Satisfied Customer, Computerworld, JAN 19, 1972, p. 1.

105. Does the Computer Know Who Made the Peripherals?, Business Automation, NOV 1971, p. 26.

106. Sales Brochures of Ampex, Calcomp, Century Data Systems.

107. More Bits/Inch by Ralph Auf der Heide, Datamation, 15 JULY 70, pp.66-71.

108. Two approaches for Increasing Storage Density in Modern Digital Computing Systems, by Neil M. Schmitt and James L. Melsa, IEEE Transactions on Computers, vol. C-20, No. 2, FEB 1971, pp. 167-175.

109. Getting it on tape - an advanced subsystem (IBM 3803/3420 tape system), Computing Report, NOV 70, p. 18.

110. Phase Encoding provides improved error correction by Frank Prasta, Computerworld, 31 MAR 71.

111. Independents have pioneered tape drive technology, Computerworld, 31 MAR 71.

112. Independents Vary on Double Density, Computerworld, 13 OCT 71, pp. 29-31.

113. Disk Replacements for Fastrand offers Better Price/Performance, Computerworld, 2 FEB 72, p. 17.

114. Univac 1108 System Description Manual, UP-4046.

115. Univac 1108 Fastrand Mass Storage Subsystem Manual, UP-4083, 1966.

116. An Easier Way to Tap Mass Data (Grumman Masstape System), Business Week, 27 NOV 71.

117. Masstape - An on-line high performance modular mass memory system, Sales brochure for Grumman Data Systems Corp.

118. An Introduction to Massive Stores, by J. W. Weil, Honeywell Computer Journal, pp. 88-92.

119. Auerbach Computer Characteristics Digest, JAN 1972, p. 305.

Distribution List

Navy Fleet Material Support Office	(2)
Naval Postgraduate School Library	(2)
Dean of Research Administration	(2)
J. R. Borsting	(1)
R. E. Gaskell	(1)
N. F. Schneidewind	(1)
G. H. Syms	(1)
T. L. Grainger	(1)
R. Carden	(1)